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Dredged Material Reclamation at the Jones Island Confined Disposal Facility

Innovative Technology Evaluation Report

SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

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Dredged Material Reclamation at the Jones Island Confined Disposal Facility

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication had been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Acting Director
National Risk Management Research Laboratory

Abstract

The Jones Island Confined Disposal Facility (JICDF) located in Milwaukee Harbor Wisconsin, receives dredged materials from normal maintenance of Milwaukee's waterways, and has done so for many years. Like many CDFs across the country, Jones Island faces the dilemma of steady inputs and no feasible alternative for expansion. The U.S. Army Corps of Engineers (USACE) in partnership with the Milwaukee Port Authority is exploring a large range of beneficial reuse options for the dredged material, from building and road fill, to landscape material.

Aged dredged material at Jones Island is heterogeneous in composition because it comes from waterway sources over a wide area over many years. Some dredged materials contain EPA listed wastes from industrial discharge, spills, and urban run-off in varying concentrations. Natural attenuation processes occur at differing rates due to random placement in the CDF and fluctuating oxygen and moisture levels and weathering impacts.

The first step taken on this project toward determining appropriate end use of the stored material was a detailed characterization across the CDF with samples taken at three depths and analyzed for PAHs, PCBs, DRO, and metals. The resultant map showed areas of high and low concentrations, and pinpointed areas of opportunity for testing. Concurrent treatability studies conducted by the USACE using crops and grasses determined that plants would survive in the material and degrade the contaminants. A corn hybrid had the highest degradation effect over the short test period.

Field plots were established on the CDF by excavating, mixing, and depositing soil in test cells. The test plots closely follow established protocols for plot size, sampling, and statistical design. The field demonstration involved four different treatment plots: hybrid corn, an indigenous willow, local grasses, and an unplanted control. The EPA Superfund Innovative Technology Evaluation Program (SITE) and USACE evaluated the demonstration for a two-year period (2001-2002). The effectiveness of the various plantings was monitored directly through soil sampling and indirectly with a variety of plant assessments.

This Innovative Technology Evaluation Report presents the results from sampling, monitoring, and modeling efforts to date.

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Acronyms, Abbreviations and Symbols

ac	ac
AQMD	Air Quality Management District
ARAR	Applicable or Relevant and Appropriate Regulation
°C	Degree Centigrade
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CDF	Confined Disposal Facility
CERCLA	Comprehensive Environmental Response, Cleanup, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
CV	Coefficient of Variation
CWA	Clean Water Act
DOER	Dredging Operations and Environmental Research
DRO	Diesel Range Organic
EPA	U.S. Environmental Protection Agency
°F	Degree Fahrenheit
ECD	Election Capture Detection
ERDC	Engineer Research and Development Center
FID	Flame Ionization Detection
ft	foot
FY	Fiscal Year
g	gram
gal	gallon (US)
GC/MS	Gas Chromatography/Mass Spectrometry
ha	hectare
HASP	Health and Safety Plan
HAP	Hazardous Air Pollutant
HAZWOPER	Hazardous Waste Operations and Emergency Response
in	inch
ITER	Innovative Technology Evaluation Report
JICDF	Jones Island Confined Disposal Facility
kg	kilogram
km	kilometer
L or l	liter
LCS/LCSD	Laboratory Control Sample/Laboratory Control Sample Duplicate
LRD	Lower Reference Datum
m	meter
mg	milligram
mi	standard mile
mm	millimeter
MS/MSD	Matrix Spike/Matrix Spike Duplicates
NAAQS	National Ambient Air Quality Standards
NOAA	National Oceanic and Atmospheric Administration
NCP	National Contingency Plan
NESHAP	National Emission Standards for Hazardous Air Pollutants

Acronyms, Abbreviations and Symbols(Cont'd)

NPDES	National Pollution Discharge Elimination System
NPL	National Priority List
NPK	Nitrogen, Phosphorous, and Potassium
NRMRL	National Risk Management Research Laboratory
O&M	Operations & Maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
ORD	Office of Research and Development
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PPE	Personal Protective Equipment
ppm	part per million
PVC	Polyvinyl chloride
QA/QC	Quality Assurance/Quality Control
RCL	Residual Cleanup Level
RCRA	Resource Conservation and Recovery Act
RTDF	Remediation Technologies Demonstration Forum
s	second
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SIM	Selective Ion Monitoring
SITE	Superfund Innovative Technology Evaluation Program
T=0	Baseline Sampling Event
T=1	Mid-Term Sampling Event
T=2	Final Sampling Event
TER	Technology Evaluation Report
TSCA	Toxic Substances Control Act
UCL	Upper Control Limit
ug	microgram
USACE	U.S. Army Corps of Engineers
VOC	Volatile Organic Compound
WDNR	Wisconsin Department of Natural Resources

Acknowledgments

This report was developed by SAIC and ARCADIS under the direction of Steven Rock, the EPA Technical Project Manager for this demonstration. Gratefully acknowledged are the participation and contributions by the USACE technical and management team, including David Bowman and Richard Price. Their tireless efforts were instrumental in making this project a success.

SECTION 1
INTRODUCTION

This section provides a discussion on the origin and need for remediation of contaminated dredged materials, the Superfund Innovative Technology Evaluation (SITE) Program, the purpose of this Innovative Technology Evaluation Report (ITER), phytoremediation technology, and introductory information concerning this phytoremediation SITE Project. For additional information about the SITE Program visit the U.S. Environmental Protection Agency (EPA) SITE Program web page at http://www.epa.gov/ORD/SITE/. For information on this SITE project and the technology involved, key contacts are listed at the end of this section.

1.1 Background

In this SITE demonstration, phytoremediation technologies were applied to contaminated dredged materials from the Jones Island Confined Disposal Facility (CDF) located in Milwaukee Harbor, Wisconsin (Figure 1-1). The Jones Island CDF is an active facility, having received dredged materials from normal maintenance of Milwaukee's waterways and tributaries for many years. Like many CDFs across the country, Jones Island faces the dilemma of steady inputs yet with no feasible alternative for expansion. One of the more attractive options for optimizing existing CDF space is to 'beneficially reuse' the dredged sediments, which effectively allows for a recycling of the sediments and the available CDF space. The U.S. Army Corps of Engineers (USACE), in partnership with the Milwaukee Port Authority, is exploring several beneficial reuse options for the dredged material, including use as building materials, road fill, landscaping soil, and other uses. However, direct beneficial reuse is not possible because a significant portion of the dredged material is considered contaminated and must be cleaned before it can be reused.

Dredged material at Jones Island is similar to many other CDFs in that the soil, pore water, and entrained contaminants are often very heterogeneous. They arise from airborne and waterway sources draining large industrialized areas over a period of many years. Dredged materials often contain USEPA listed wastes generated from airborne and regulated industrial discharges, spills, and urban run-off. Dredged materials used in the SITE demonstration were contaminated with polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and diesel-range organics (DRO) at levels exceeding applicable Wisconsin Department of Natural Resources (WDNR) and USEPA standards.

This demonstration project was designed to evaluate and compare different treatment schemes for feasibility to remediate Jones Island CDF material to applicable or relevant and appropriate regulations for beneficial use of dredged materials containing PAHs, PCBs and DRO. Three plant-based and one microbe-based treatments were evaluated.

1.2 Brief Description of the SITE Program and Reports

The SITE Program is a formal program established by EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE Program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of three major elements described below:

- Demonstration Program
- Monitoring and Measuring Technologies Program.
- Technology Transfer Program.

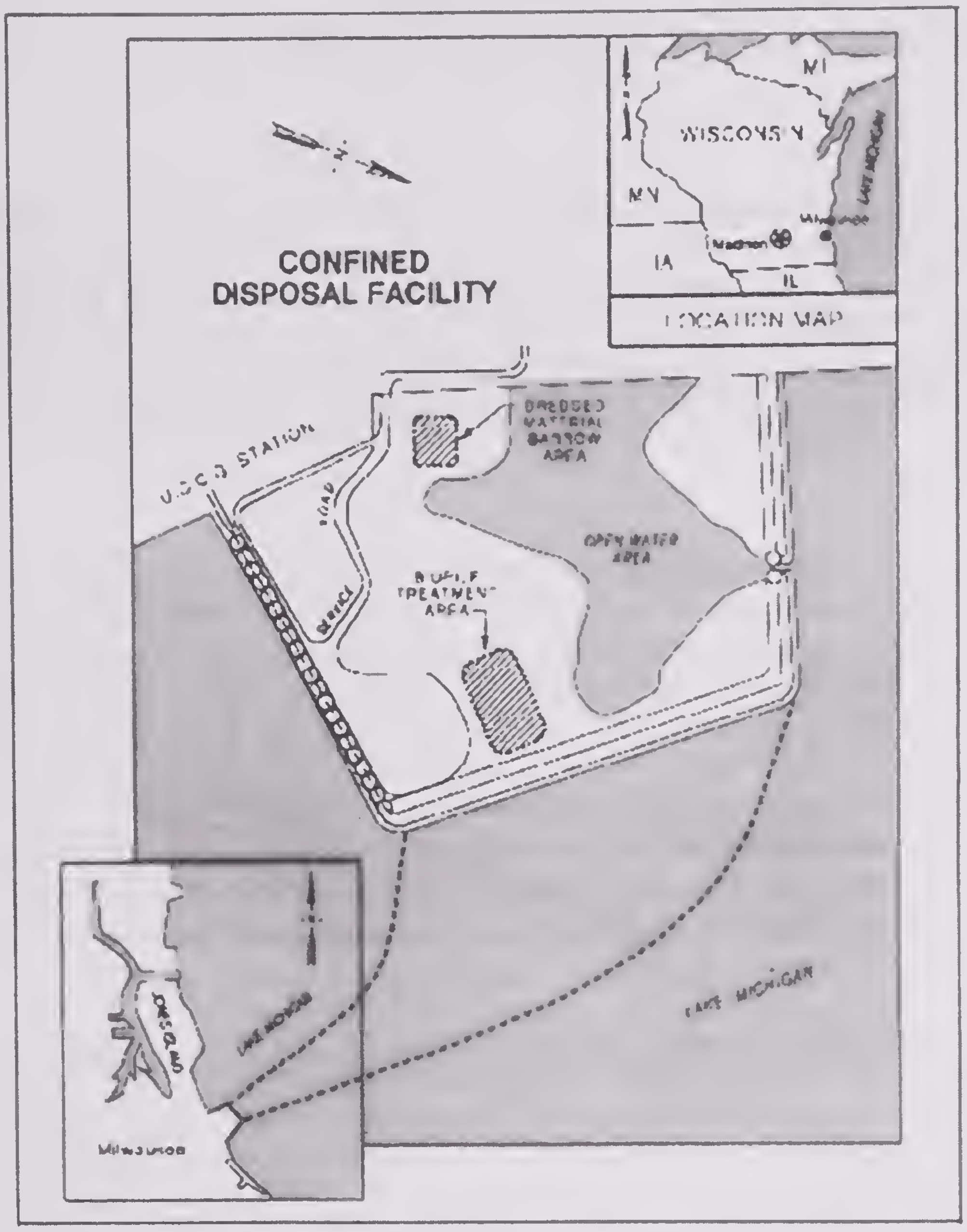

Figure 1-1. Location of Jones Island CDF

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative technologies so that potential users can assess the technology's site-specific applicability. Technologies evaluated are either available commercially or imminently so. SITE demonstrations usually are conducted on hazardous waste sites under conditions that closely simulate actual operations, thus producing useful, reliable information. Data collected are used to assess: (1) the performance of the technology, (2) the potential need for pre- and post-treatment processing of wastes, (3) potential operating problems, and (4) the approximate costs. These field trials also provide opportunities to evaluate the long-term risks, capital and operating costs associated with full-scale application of the subject technology, and limitations of the technology.

New devices and test procedures that improve field monitoring and site characterizations are identified and tested in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates the protocols and standard operating procedures for demonstrating methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstration, and the Monitoring and Measurement Technologies Programs through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and

remediation at Superfund and other hazardous waste sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

1.3 The SITE Demonstration Program

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff review the proposals to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile and in-situ technologies are of particular interest.

Once EPA has accepted a proposal, cooperative agreements between EPA and the technology developer establish responsibilities for conducting the demonstration and evaluating the data. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transport, operations, and removal of the equipment. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of this evaluation at the Jones Island CDF are published in this ITER. A companion Technology Evaluation Report (TER) is available as a supporting document to the ITER. The ITER contains detailed information concerning sampling and sampling strategy, cited analytical procedures along with detailed descriptions of non-standard procedures, all supporting QA/QC information, and relevant information concerning project design not contained in the ITER. The ITER is available upon request from the EPA. (See contact information at the end of this section.) The ITER is intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste. The function of the ITER is explained below.

1.4 Purpose of the Innovative Technology Evaluation Report

This ITER provides information on the Jones Island CDF project including a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision makers responsible for implementing remedial actions.

To encourage consideration of demonstrated technologies, EPA provides information regarding the applicability of each technology to other sites and wastes. The ITER includes information on cost and performance as observed during the demonstration. It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE demonstration focuses on the performance of a technology in treating a specific waste. The waste characteristics of other sites may differ from the characteristics of the treated waste. Therefore, a successful or failed field demonstration of a technology at one site does not necessarily ensure that it will similarly succeed or fail at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.5 Technology Description

1.5.1 General Technology Description

Phytoremediation represents a group of innovative technologies that use plants and natural processes to remediate or stabilize hazardous wastes in soil, sediments, surface water, or groundwater. The term phytoremediation, used widely in the literature prior to 2001, has more recently been supplanted by the term phytotechnologies, in recognition of a more broad range of plant-facilitated processes involved (ITRC, 2001).

Phytotechnologies use plants as agents to remediate various media impacted with different types of contaminants, and can be implemented either in situ or ex situ. Phytotechnologies have been successfully demonstrated in laboratory, bench-scale, or full scale projects involving:

- Organic contaminants, including petroleum hydrocarbons, gas condensates, crude oil, chlorinated compounds, pesticides, PCBs, and explosive compounds.
- Inorganic contaminants, including salts, heavy metals, metalloids, nutrients, and radioactive materials.

Effective design of a phytotechnology system requires a clear understanding of its mechanisms and associated benefits and limitations. A proper phytotechnology system must be designed, developed, and implemented using detailed knowledge of the site layout, soil characteristics, hydrology, climate conditions, analytical needs, operations and maintenance requirements, economics, public perception, and regulatory environment (ITRC, 2001).

Phytoremediation relies upon natural systems. Thus, it is often more easily adaptable to varied sites. Over the last decade, phytoremediation has been (and continues to be) evaluated at a variety of sites and on myriad contaminants to determine the conditions under which phytoremediation systems are effective in reducing contamination.

Because it is based on natural processes, phytotechnologies research represents a progression of discoveries of how these natural processes interact with contaminated media. In this sense, phytotechnologies are being 'discovered' more so than they are being 'invented' or 'developed'. This SITE report is an attempt to advance the phytotechnology knowledge base by deploying the technology at the Jones Island CDF, and then observing and reporting the results.

1.5.2 Detailed Technology Description

Phytoremediation, or phytotechnologies, are currently defined as "The use of vegetation to contain, sequester, remove, or degrade organic and inorganic contaminants in soils, sediments, surface water, and groundwater (EPA, 2000).

Six different plant-facilitated processes have been recognized as contributing to phytoremediation success. These processes are as follows:

- Phytoaccumulation, referring to a process where plant roots uptake and translocate contaminants (typically metals and radionuclides) to their above-ground biomass where they are concentrated and can be harvested and disposed of.
- Rhizostabilization, which refers to a process whereby contaminants (typically metals) are sorbed onto plant roots and therefore not available for migration.
- Rhizodegradation, which describes the complex interactions of roots, root exudates, and the surrounding soil and microbial community, and how these interactions can break down contaminants, (typically organics) in situ to less toxic or non-toxic by-products.
- Phytodegradation, which describes processes occurring inside the plant which can degrade or detoxify contaminants, (usually organics).
- Phytovolatilization, referring to the process whereby contaminants are extracted from soil or ground water and then transferred into the atmosphere via evapotranspiration processes, (more typical of organics).
- Phytostabilization, which describes how certain plants which have high water use (typically trees) can slow or reverse ground water flow paths thereby containing, and often remediating, contaminated groundwater plumes.

Of these six processes, rhizodegradation is emerging as one of the most important, and complex, means by which plants degrade contaminants, especially large molecule organics like PAHs and PCBs found at the Jones Island CDF. 'Phytostabilization' can be important in dewatering dredged sediments using high evapotranspiration plants (e.g. hybrid poplar or willow). The other phytotechnology processes described

above were not thought to be significant contributors to the remediation of PAH and PCB contaminated sediments during this SITE project.

The rhizosphere is generally described as an area within 1 mm to 3 mm of the nearest plant root (Schnoor, 1997). Rhizodegradation occurs when roots exude complex secretions containing carbohydrates that feed and stimulate local microorganisms, which may result in respiration of organic contaminants.

Rhizodegradation has two recognized components: 1) Biodegradation, which converts contaminants to food source for the plants, and 2) Cometabolism, in which bioactivity degrades the contaminant without providing a direct food source for the plant.

Biodegradation refers to breakdown of contaminants in the soil through bioactivity in the rhizosphere. This bioactivity is facilitated by proteins and enzymes produced and exuded by plants or from soil organisms such as bacteria, yeast, and fungi. Many organic contaminants can be broken down into harmless products or converted into a source of food and energy for the plants or soil organisms, or both (Donnelly and Fletcher, 1994).

Cometabolism describes how natural substances released by the plant roots (i.e., sugars, alcohols, carbohydrates, and acids) contain organic carbon which provide food for soil microorganisms, thereby enhancing their biological activities.

Thus, the root zone processes of biodegradation and cometabolism, collectively referred to as rhizodegradation, are thought to represent the primary mechanism through which PAHs, PCBs and other organic contaminants in Jones Island CDF material might be remediated.

1.6 Jones Island/SITE Background

The first step taken on this project toward determining appropriate beneficial end use of the dredged material present in the CDF was a detailed characterization across the CDF with samples taken at three intervals below ground surface and analyzed for PAHs, PCBs, and agricultural parameters. DRO analysis was also run to determine if the less expensive DRO test could be substituted for PAH testing. The analytical results confirmed the heterogeneity of the material, revealing a wide variety of contaminant concentrations and also indicating areas of opportunity for phytoremediation.

Treatability studies conducted at the USACE Engineer Research and Development Center (ERDC) in 2000 by the technology developer using crops and grasses determined that plants would survive in the material and degrade the contaminants. Over the short test period, a fast-maturing corn hybrid showed the highest reduction effect. (See section 4.5.2 for more details).

In June 2001, four field plots containing four treatment cells each were established on the CDF by excavating, screening, and depositing soil in the cells. The test plots closely followed the Remediation Technology Development Forum (RTDF) protocol for plot size, sampling, and statistical design. The RTDF Protocol is available at http://www.rtdf.org/public/phyto/protocol/protocol99.htm. Each plot had four randomized treatments: a corn hybrid, sandbar willow, local grasses, and a n unplanted control. Corn was planted twice during the growing season, which was designated as June through September.

Figure 1-2 shows an "as-built" layout of the Jones Island test plots and irrigation system. This photo was taken during the an early stage of the first growing season in 2001. Figure 1-3 is a schematic of the test plot/treatment cell configuration including construction details.

Figure 1-2. Layout of Treatment Plots at Jones Island CDF

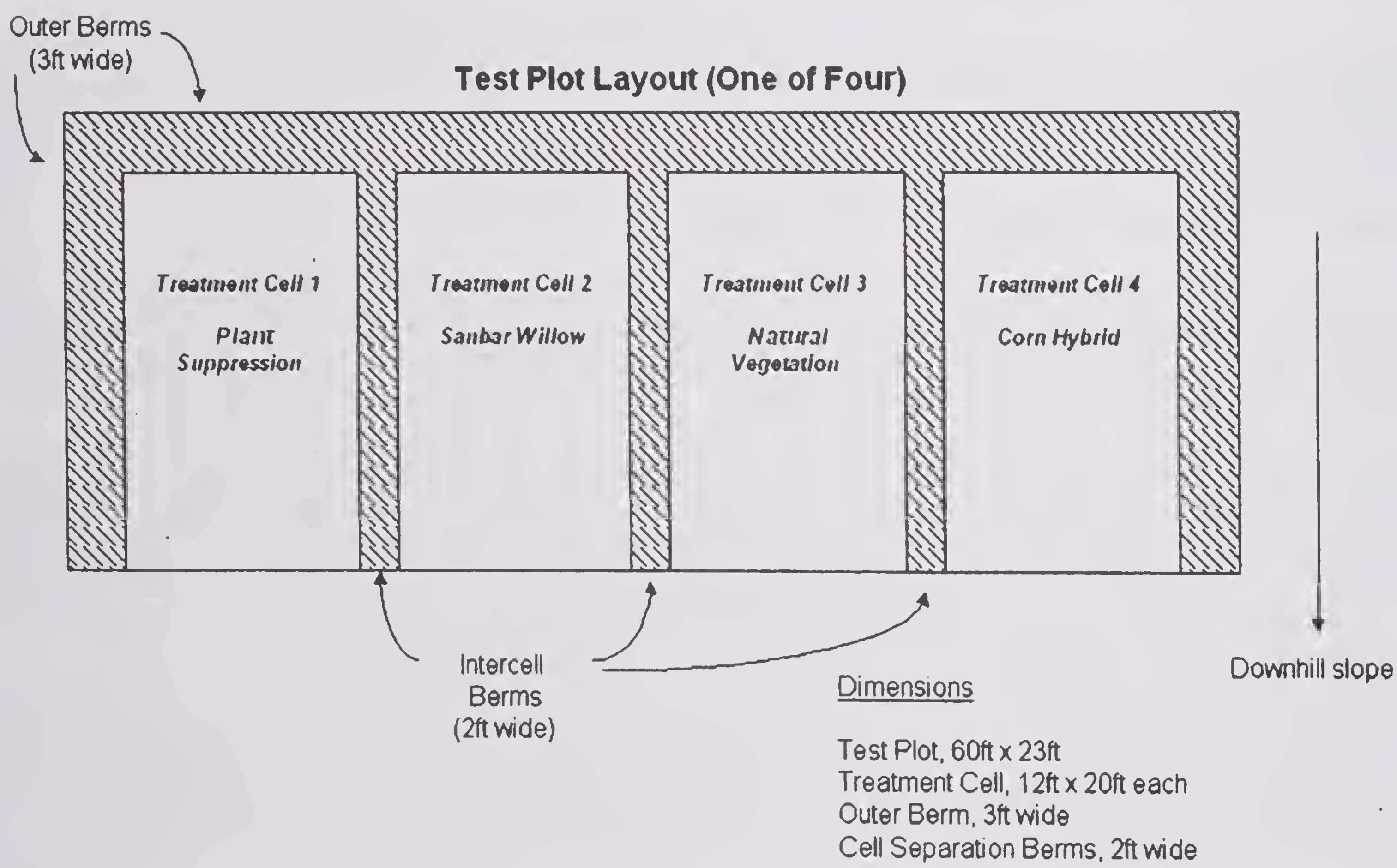

Figure 1-3. Test Plot and Treatment Cell Configuration

1.7 Key Contacts

Additional information on the Jones Island CDF field demonstration and the SITE Program can be obtained from the following sources:

This SITE Demonstration:
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Information on the SITE Program also is available through the following on-line information clearinghouses:

- The Hazardous Waste Clean-up Information Web Site provides information about innovative treatment technologies to the hazardous waste community. It describes programs, organizations, publications and other tools for federal and state personnel, consulting engineers, technology developers and vendors, remediation contractors, researchers, community groups and individual citizens. CLU-In may be accessed at http://www.clu-in.org/.
- EPA REmediation And CHaracterization Innovative Technologies (REACH IT) is a system that lets environmental professionals use the power of the Internet to search, view, download and print information about innovative remediation and characterization technologies. EPA REACH IT will give you information about more than 650 service providers that offer almost 1,300 remediation

technologies and more than 150 characterization technologies. EPA REACH IT combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications. used and the service providers that offer them. EPA REACH IT can be accessed at http://www.epareachit.org/.

Technical reports may be obtained by contacting the Center for Environmental Research Information (CERI), 26 West Martin Luther King Drive in Cincinnati, Ohio, 45268 at 1-800-490-9198 or (513) 569-7562.

Section 2
Technology Applications Analysis

2.1 Key Features

Phytoremediation is a relatively low-cost, remediation technology that produces little or no process residual, Compared to tradition electro-mechanical remediation methods, phytoremediation systems generally require less long-term operational and maintenance effort and cost.

Phytoremediation is a solar-energy driven, passive technique that is applicable for the remediation of sites having low to moderate levels of contaminants at shallow depth. Depending on the nature of contamination problems at a site and its particular hydrogeologic setting, plant species are selected based on these characteristics:

- Growth rate and yield
- Evapotranspiration potential
- Production of degradative enzymes
- Depth of root zone
- Contaminant tolerance
- Bioaccumulation ability.

Despite the fact that most of what is known about this technology is derived from laboratory and small-scale field studies, phytotechnologies have received higher public acceptance than most conventional remedial options. Phytoremediation systems can be used along with or, in some cases, in place of intrusive mechanical cleanup methods. Compared to mechanical treatment approaches, plant-based remediation systems generate fewer air and water emissions, generate less secondary waste, and generally cost much less and have the advantage of being an in-situ technology.

2.2 Operability of the Technology

This discussion on technology operability will summarize several design considerations for site-wide, scaled-up phytoremediation systems planted in shallow soils or solids such as those at the Jones Island CDF.

A wide variety of plant types may be used in this application, from ground cover and grasses to trees. Mechanisms of contaminant degradation by plants is described in section 1. For the Jones Island CDF SITE project, rhizodegradation in the root zone is the dominant process by which remediation of PAHs and PCBs would be expected to occur.

Full-scale design considerations include plant selection, site preparation, planting density and methods, distribution and dimensions of plots, agronomic conditions, irrigation and maintenance requirements, all of which are highly site specific. It is becoming increasingly apparent that the design and monitoring of phytoremediation systems can be at least as complex as many traditional mechanical remediation methods. Designers of phytotechnology systems, who often rely heavily on the biological and ecological sciences, should not assume that plant-based phytotechnologies are inherently simplistic. In fact, the site-specific, complex nature of phytotechnology systems needs to be recognized by all concerned parties prior to deployment of the plants. Factors that affect the operability of a phytoremediation system include, but are not limited to:

- Hydraulic framework, (depth to groundwater, seasonal flucuations, plume configuration and movement)
- Physical and chemical properties of the soil (both contaminant and agronomic chemistry)
- Distribution and magnitude of contamination (degree of heterogeneity)

- Climatic conditions
- Site characteristics and land features (access by people or animals to the treatment area) and
- Treatment goals.

For a soil remediation application, effective phytoremediation system is dependent upon an adequate and even distribution of plant roots throughout the target area. It is therefore important to identify, and if economically feasible, eliminate any obstacles or restrictive features on a property that might hamper the effective placement or growth of the selected plants. The site should be cleared of any above-ground or below-ground obstructions that might interfere with the establishment and health of the remediation plots.

An understanding of the physical and chemical properties of the contaminated soil is important in knowing what adjustments need to be made to the soil to foster healthy plant growth, including vigorous root growth. Soil condition is also a factor in determining appropriate planting procedures. The soil in a proposed plot area might require reworking by plowing and discing appropriate mixtures of fertilizer and amendments (i.e., organic matter, drainage-enhancing media) into the upper portions of the soil profile. Soil moisture retention, soil moisture profiles, drainage and infiltration rates factor into decisions regarding the necessity of an irrigation system or ground cover.

Climatic conditions at a site need to be evaluated with regard to selecting appropriate plant type, determining the arrangement and size of the plots, and assessing the need for an irrigation system. Ideally, the plants should be obtained locally to ensure that the species is well adapted to the local climate and less susceptible to disease.

2.3 Applicable Wastes

A biomound study conducted by the USACE Detroit District in 1998 at the Jones Island CDF concluded that there were indigenous microorganisms within the dredged material capable of degrading PAH and PCB compounds (Bowman, 1999). Subsequent greenhouse studies conducted in 2000 by the USACE ERDC suggested that plants could stimulate and enhance the actions of the microbes within the dredged material. PAHs and PCBs are fairly insoluble compounds, with log Kow values in excess of 3. These and similarly insoluble organic compounds (e.g. DRO) are not likely candidates for plant uptake. It is hypothesized that rhizodegradation (see section 1.5.2) is the primary treatment mechanism for these and other similar wastes.

2.4 Availability and Transportability of the Equipment

The availability of phytoremediation "equipment" is generally not a barrier to development. Site preparation equipment is typically farming-type or construction-type and readily available. Materials for soil amendments are similarly available. Plant materials used in phytoremediation systems can usually be found at local nurseries, through industry sources, or via the Internet. Equipment necessary for monitoring phytoremediation systems might include standard, inexpensive, and readily available equipment (i.e. soil moisture probes, weather stations, etc.) or may include more specialized and expensive instruments (e.g. sap flow gauges, leaf index analyzers, etc.).

Equipment used in phytoremediation is easily transportable. Farming equipment may require large trailers to mobilize, and large trees incorporated into a design may also require out-sized equipment. Other tools used in phytoremediation systems (hand tools, plant seed or seedlings, etc) are easily transportable.

Phytoremediation is generally considered a single-use technology. Plants deployed at one site are not removed and redeployed at another site. In this sense the technology is not "transportable".

2.5 Materials Handling Requirements

For the proper preparation of dredged sediments for planting, certain areas might require some degree of in-situ material handing. Handling is defined as plowing, tilling, and discing to facilitate fertilizer infiltration, increase soil porosity, ease planting and foster vigorous root growth.

In addition to the contaminated material handling, operators might also need to handle fertilizer, pesticides, and other agronomic amendments. Fertilizer and soil conditioning components could include any variety of commercial fertilizer mixes, organic carbon, aged manure, sewage sludge, compost, straw and mulch. A mix mill/grinder and spreader might be needed for handling the fertilizer and subsurface combs (portable vibrating screens) may also be necessary to remove debris and cobbles from the soil and to remove debris from soil conditioning material.

Contaminated, dredged material is subject to specialized handling, storage and disposal requirements: testing or deploying phytotechnologies offers no relief from these requirements. A full description of the regulatory and handling requirements for contaminated media likely to be found in a given CDF are beyond the scope of this document.

Since rhizodegradation does not translocate or accumulate contaminants in above-ground biomass, plant materials used for the phytoremediation of PAHs and PCBs generally do not require special handling.

2.6 Site Support Requirements

Site support requirements for phytoremediation systems occasionally include one or more of the following:

- Electricity to run groundwater pumps or other circulatory system, which can be utility-connected or solar powered
- Water, for irrigation, which may be spray, flood, or drip-applied, and may be contaminated or clean in origin
- Any equipment deemed necessary for site monitoring and maintenance (e.g. soil moisture probes, sap flow equipment, data loggers, telemetry)
- Personnel or animal fencing, depending on the site location, plant sensitivity hazard analysis, etc.

2.7 Range of Suitable Site Characteristics

Generally, any given location which supports or can support plant life probably has characteristics suitable for some form of phytotechnology application. However, while the range of suitable site characteristics is wide, there are significant limitations to the technology as described in the following section.

To determine the suitability of the dredged materials at the Jones Island CDF, grab soil samples were collected and analyzed for various agronomic parameters as part of a scoping study in September 2000. Similar sampling and analysis was performed again at the start of the test period in June 2001. Table 2-1 compares results from the eventual borrow area identified during the scoping study (GP17 and GP19) with the mean (n=16) of baseline sampling after the dredged material was placed into the treatment cells (before fertilizer was applied). The data between the two sampling events agrees well and was considered suitable by the USACE for the purposes of this field demonstration.

Insect attack and available responses may limit plant choices from both a physical and regulatory standpoint. During the second half of the 2002 growing season, the hybrid corn crop and adjacent natural vegetation became infested with the Western Corn Rootworm Beetle (*Diabrotica virgifera virgifera*). The pest is well known in agriculture, and a number of commercial pesticides are available as well as other natural organic and biological controls, all with varying degrees of predicted success. Sevin, a non-restricted carbamate insecticide available at local garden shops, was selected for use at the demonstration site. A license was not required for its use. Several applications were required.

Table 2-1. Borrow Area and Baseline Levels of Agronomic Parameters

Parameter	Borrow Area		Baseline
	GP17	GP19	Mean
Soil pH	8.2	7.9	8.6
Soluble Salts (mmhos/cm)	0.37	0.33	0.61
Excess Lime	Hi	Hi	Hi
Organic Matter (%)	3.8	5.0	4.1
Nitrate-Nitrogen	3	3	9.5
Phosphorous	58	69	63
Potassium	80	140	100
Sulfur	37	17	49
Calcium	4100	4100	4300
Magnesium	160	190	140
Sodium	170	31	610
Zinc	16	16	60
Cation Exchange Capacity (milliequivalents/100 g soil)	23	22	26

All concentrations in mg/kg unless otherwise noted
pH is reported as $-\log[H^{+}]$
"Hi" indicates potential for iron chlorosis or injury from pesticide carryover

2.8 Limitations of the Technology

The most significant limitation to successful phytotechnology is plant mortality. While plants need not necessarily be in perfect or optimum health to perform satisfactorily, they must be living. Therefore, toxicity to the plants, whether it arises from extreme contamination levels, poor quality soils, inadequate moisture, too short a growing season, disease or pests, must be prevented.

Limitations to phytoremediation can also arise proportionately. For example, plants may be selected which survive and perform well in a PAH-contaminated CDF in Alaska. However, the benefit might be offset by the extended time frame to achieve treatment goals due to the short growing season. Poor soils, inadequate moisture, and other factors which may not result in plant mortality may produce a proportionate limitation on a given phytotechnology application.

Similarly, inadequate root development can pose a limitation to phytoremediation effectiveness. Root mass must develop sufficiently to reach and achieve an effect on pollutants. At the Jones Island CDF project, however, root depth is not a key factor since the dredged material treatment cells were less than 30 cm (12 in) deep (easily within the reach of plant roots), and are not likely to be much deeper in a full scale operation. Depending on plant spacing, lateral root development can be important Phytoremediation designers should strive for a planting density high enough for full subsurface coverage at crop maturity, and for full above-ground 'canopy' closure to crowd out weeds which compete for space and resources (i.e. water, nutrients, and sunlight).

In general, the growing season at the Jones Island CDF is expected to commence in May. October typically brings colder weather that is unsuitable for growing the types of plants involved in this demonstration and limits

effectiveness over these months. However, rhizosphere processes can continue for short periods without living plants above offering some degree of remedial benefit even during dormant periods.

2.9 Technology Performance versus ARARs

This section discusses federal environmental regulations that act as drivers for waste cleanups across the country. These "applicable or relevant and appropriate requirements," which are referred to as "ARARs," are presented in Table 2-2 at the end of this section. In this section, the ARARs are reviewed with respect to the SITE demonstration. Readers are advised that state and local requirements, which are described only briefly in this section, may be more stringent.

2.9.1 Comprehensive Environmental Response, Compensation, and Liability Act

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by SARA in 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment. As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for remedies that are reliable and provide long-term protection. It directs EPA to do the following:

- Use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants
- Select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible.

In general, two types of responses are possible under CERCLA: removal and remedial action. Superfund removal actions are conducted in response to an immediate threat caused by a release of a hazardous substance. Many removals involve small quantities of waste of immediate threat requiring quick action to alleviate the hazard. Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances or pollutants. The phytoremediation system is likely to be part of a CERCLA remedial action.

Phytoremediation systems will in general meet most of the SARA criteria. It is an in situ treatment technology, thus the treatment process occurs in place and the removal of the contamination is permanent and protective to human health and the environment; the volume and mobility of organics in the soil is reduced to help prevent the migration of contamination off-site or to uncontaminated water supplies; phytoremediation reduces the toxicity of the treated waste media (soil or groundwater); and phytoremediation is cost-effective and an alternative treatment technology.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

The CDF demonstration site is not part of a Superfund site; therefore, CERCLA/SARA does not provide the appropriate requirements for remediation. The goal of this demonstration is to evaluate whether phytoremediation can reduce contaminants to levels that, under federal and state of Wisconsin regulations, would allow the material to be removed from the CDF for beneficial reuse.

2.9.2 Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA), an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities. It was passed in 1976 to address the problem of how to safely dispose of the enormous volume of municipal and industrial solid waste generated annually. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities. The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA.

RCRA regulations define and regulate hazardous wastes. These regulations are only applicable to the phytoremediation system if RCRA-defined hazardous wastes are present. If soils are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), essentially all RCRA requirements regarding the management and disposal of this hazardous waste will need to be addressed by the remedial managers. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. RCRA regulations do not apply to sites where RCRA-defined wastes are not present.

Unless they are specifically delisted through delisting procedures, hazardous wastes listed in 40 CFR Part 261 Subpart D remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination levels in the resulting effluent streams and residues. This implies that even after remediation, treated wastes are still classified as hazardous wastes because the pre-treatment material was a listed waste.

For generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported off-site), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (partially promulgated). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

The Jones Island CDF is a disposal facility for contaminated dredged sediments. This disposal facility does not accept hazardous waste; therefore, RCRA is not relevant or appropriate for the treatment technology occurring on-site. The goal of this demonstration is to evaluate whether phytoremediation can reduce contaminants to levels that under federal and state regulations would allow the material to be removed from the CDF for beneficial reuse.

2.9.3 Clean Air Act

The Clean Air Act (CAA) establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants such as vinyl chloride, arsenic, asbestos and benzene. States are responsible for enforcing the CAA. To assist in this, Air Quality Control Regions (AQCR) were established. Allowable emission limits are determined by the AQCR, or its sub-unit, the Air Quality Management District (AQMD).

These emission limits are based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Fugitive emissions from the phytoremediation system may come from (1) soil conditioning and plot construction and (2) periodic sampling activities. Soil moisture should be managed during system installation to prevent or minimize the impact from fugitive emissions. Although rhizospheric biodegradation and breakdown of chemicals through metabolic activities within plant tissue are components of phytoremediation, these processes as they relate to this technology are not well understood. There is some concern that organic contaminants are only partially broken down, implying that an unknown portion of the original contaminants and its daughter products may be released to the atmosphere during evapotranspiration.

Phytovolitilization can be an important process when using high evapotranspiration plants to remove chlorinated solvents from ground water plumes. However, the larger-molecule contaminants in the Jones Island material are not amenable to phytovolitilization and as such no air permits are required for the phytoremediation system as operated at the CDF.

2.9.4 Clean Water Act

The objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical and biological integrity of the nation's waters by establishing federal, state, and local discharge standards. If treated water is discharged to surface water bodies or Publicly Owned Treatment Works (POTW), CWA regulations will apply. A facility desiring to discharge water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When a NPDES permit is issued, it includes waste discharge requirements. Discharges to POTWs also must comply with general pretreatment regulations outlined in 40CFR Part 403, as well as other applicable state and local administrative and substantive requirements.

Other than the plant and tree's capacity to use surface/ groundwater, phytoremediation technologies generally do not involve the mechanical pumping, treatment and discharge of surface/groundwater. In a few rare cases where contaminated groundwater occurs at depth, mechanical pumping might be used to bring the water to the surface where it would then be applied to the plants via drip irrigation. Since this water technically would likely be completely utilized by the phytoremediation system it would not be discharged to a navigable waterway and it is unlikely that a NPDES permit will apply.

At the CDF, water for the drip irrigation system was obtained from Lake Michigan located adjacent to the demonstration site. This CDF was constructed with a grout or bentonite slurry. Although a filter system is also located along a portion of the northern wall; it is generally assumed that water entering the CDF (rainfall, water associated with dredged sediment, and groundwater recharge from the west) is lost though evaporation. A NPDES permit was not required for the phytoremediation system operated at the CDF.

2.9.5 Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards. The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. These drinking water standards are expressed as maximum contaminant levels (MCLs) for some constituents, and maximum contaminant level goals (MCLGs) for others. Under CERCLA (Section 121 (d) (2) (A) (ii)), remedial actions are required to meet the standards of the MCLGs when relevant. Since the phytoremediation system at the CDF is targeting the shallow soils, it is not likely that these standards would be applicable.

However, if a phytoremediation system is targeting groundwater, Parts 144 and 145 discuss requirements associated with the underground injection of contaminated water. If processing pumped, contaminated groundwater through the plantation's drip irrigation system is an option, approval from EPA for constructing and operating the phytoremediation system in this mode will be required.

2.9.6 Toxic Substances Control Act

The Toxic Substances Control Act (TSCA) of 1976 grants the U.S. EPA authority to prohibit or control the manufacturing, importing, processing, use, and disposal of any chemical substance that presents an unreasonable risk of injury to human health or the environment. These regulations may be found in 40 CFR Part 761; Section 6(e) deals specifically with PCBs. Materials with less than 50 ppm PCB are classified as non-PCB; those containing between 50 and 500 ppm are classified as PCB-contaminated; and those with 500 ppm PCB or greater are classified as PCB. PCB-contaminated materials may be disposed of in TSCA-permitted landfills or destroyed by incineration at a TSCA-approved incinerator; PCBs must be incinerated. Sites where spills of PCB-contaminated material or PCBs have occurred after May 4, 1987 must be addressed under the PCB Spill Cleanup Policy in 40 CFR Part 761, Subpart G. The policy establishes cleanup protocols for addressing such releases based upon the volume and concentration of the spilled material.

The CDF is a disposal facility for contaminated dredged sediments, including detectable concentrations of PCBs. The concentrations of PCBs identified in the surface soils at the CDF ranged from non-detectable to less than 5 ppm. TSCA regulations under 40 CFR 761.61(a)(4)(i)(A) establish 1 ppm PCBs as the cleanup level for sediments (referred to as "*bulk PCB remediation waste*") in "*high occupancy areas.*" One of the goals of this demonstration is to evaluate whether phytoremediation occurring primarily through enhanced rhizospheric bioremediation can reduce PCBs to levels that under TSCA would allow the material to be removed from the CDF.

2.9.7 Occupational Safety and Health Administration Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the Occupational Safety and Health Administration (OSHA) requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

Technicians involved with the construction and operation of a phytoremediation system may be required to have completed an OSHA training course and be familiar with OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of an acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and as a medical baseline, (3) periodic examinations (usually annual) to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known overexposure, and (5) an examination at termination of employment.

For most sites, minimum personnel protective equipment (PPE) for workers will include gloves, hard hats, steel-toe boots, and Tyvek® coveralls. Depending on contaminant types and concentrations, additional PPE may be required, including the use of air purifying respirators or supplied air. At the Jones Island CDF, noise levels are not expected to be high, except during the ground preparation and potentially during the planting phase which will involve the operation of heavy equipment. During these activities, noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, workers will be required to wear hearing protection. The levels of noise anticipated are not expected to adversely affect the community, but this will depend on proximity to the treatment site.

2.9.8 State Requirements

State and local regulatory agencies may require permits prior to the operation of a phytoremediation system. Most federal permits will be issued by the authorized state agency. An air permit issued by the state Air Quality Control Region may be required if air emissions in excess of regulatory criteria, or of toxic concern, are anticipated. Local state agencies will have direct regulatory responsibility for environmental media issues. If remediation is at a Superfund site, federal agencies, primarily the U.S. EPA, will provide regulatory oversight. If off-site disposal of contaminated waste is required, the waste must be taken to the disposal facility by a licensed transporter.

Table 2-2. Federal and State Applicable or Relevant and Appropriate Requirements for the Phytoremediation System

Process Activity	ARAR	Description	Comment
Characterization of untreated waste	RCRA: 40 CFR 261 (or State Equivalent)	Untreated waste should be characterized to determine if it is a hazardous waste, and if so, if it is a RCRA-listed waste.	If applicable perform chemical and physical analyses.
Site preparation activities related to system installation	OSHA: 29 CFR 1910.120	Personnel need to be protected from volatile emissions and airborne particulate during soil boring and excavation activities. Personnel need to be provided with protective equipment and be involved in a medical monitoring program.	Provide air monitoring equipment during site preparation and planting; Provide personal protection equipment as necessary.
Waste processing using Phytoremediation technology	RCRA: 40 CFR 264 Subpart J and 270 (or State Equivalent)	Treatment of a RCRA hazardous waste requires a permit. If non-RCRA waste, then a permit or a variance from the State hazardous waste agency may be required.	If activity is conducted within a one year time period,a full RCRA permit may not be required.
Cleanup standards are established	SARA Section 121(d)(2)(A)(ii); SDWA: 40 CFR 141	Remedial actions of surface and groundwater are required to meet MCLGs (or MCLs) established under SDWA.	If applicable for surface and groundwater; relevant and appropriate if drinking water source could be affected.
	SARA Section 121(d)(2)(A)	Site-specific Remediation Goals can be established through the Record of Decision (ROD). Remediation Goals may be developed during treatability work for treatment of soil.	If applicable, relevant and appropriate.
Storage of waste	RCRA: 40 CFR Part 264 Subpart J (or State Equivalent)	Storage tanks for recovered liquid waste must be placarded appropriately, have secondary containment, and be inspected daily.	If storing non-RCRA wastes, RCRA requirements are still relevant and appropriate. Liquid wastes generated may include decontamination rinsates
	RCRA: 40 CFR Part 264 Subpart I (or State Equivalent)	For non- CDF sites, containers of contaminated soil from excavation activities may need to be labeled as a hazardous waste, the storage area needs to be in good condition, weekly inspections should be conducted, and storage should not exceed 90 days unless a storage permit is acquired.	CDFs are disposal facilities; contaminated materials are managed on site. If applicable for RCRA wastes; relevant and appropriate for non-RCRA wastes.

Table 2-2 (Cont'd). Federal and State Applicable or Relevant and Appropriate Requirements for the Phytoremediation System

Process Activity	ARAR	Description	Comment
Waste Disposal	RCRA: 40 CFR Part 262; SARA Section 121 (d)(3)	Generators of hazardous waste must dispose of the waste at a facility permitted to handle the waste. Wastes generated include soil cuttings and recovered liquid waste. Generators must obtain an EPA ID No. prior to waste disposal.	Not applicable: CDF is a disposal facility. Only remediated soils that meet federal standard will be removed from the site.
	CWA: 40 CFR Parts 403 and/or 122 and 125	Discharges of non-hazardous wastewater to a POTW must meet pre-treatment standards; discharges to a navigable water must be permitted under NPDES.	Applicable and appropriate for decontamination rinsates.
	SDWA: 40 CFR Parts 144 and 145	Specifies standards that apply to the disposal of contaminated wastewater in underground injection wells. Permission must be obtained from U.S. EPA to use existing permitted underground injection wells or to construct and operate new wells.	Applicable if underground injection is selected as a disposal means for contaminated wastewater.
	RCRA: 40 CFR Part 262 and 263 (or State Equivalent)	Hazardous wastes transported off-site for treatment or disposal must be accompanied by a hazardous waste manifest, and must meet packaging and labeling requirements. Hazardous waste haulers must be EPA-licensed.	Not applicable: CDF is a disposal facility. Only remediated soils that meet federal standard will be removed from the site.
	RCRA: 40 CFR Part 268	Hazardous wastes must meet specific treatment standards prior to land disposal, or must be treated using specific technologies.	Not applicable: CDF is a disposal facility. Only remediated soils that meet federal standard will be removed from the site.

Section 3
Economic Analysis

3.1 Introduction

This economic analysis presents cost estimates for using phytoremediation to treat contaminated dredged material in CDFs. The cost estimates are based on the results of the SITE demonstration that utilized four replicated test plots at the Jones Island CDF in Milwaukee, Wisconsin. This economic analysis estimates expenditures for remediating a total volume of 1,613 yds^3 (1 acre surface area, 1 foot deep) of dredged soil by phytoremediation. Two phytoremediation treatments are considered in this analysis: treatment plots planted with sweet corn (corn treatment) and treatment plots planted with willow trees (willow treatment).

Consistent with standard practice in the United States and in keeping with the typical expanse of CDFs in general, costs have been estimated on an acre foot basis. This unit of measure is particularly relevant to the Jones Island project because the demonstrated technology was applied to the upper foot of dredged material with the intent being to remediate the upper foot, remove the upper foot, and subsequently apply the phytotechnology to the next underlying one foot lift of dredged material.

The actual SITE demonstration treated approximately 142 yds^3 of dredged material in 16 treatment cells with an overall dimension of 60 feet by 23 feet. Dredged material was passed through a soil screener, placed in the cells using a front-end loader, tilled with a rotary tiller, and leveled with a drag. For purposes of this economic analysis, the remediation is anticipated to be performed on dredged material in-place, and it is assumed that each treatment area will be graded, tilled, planted, fertilized and irrigated. Estimated costs do not include excavation or hauling of treated soils off site. No additional run-off controls are assumed other than the existing CDF structure. The cost estimates provide adequate detail such that if a greater area is treated, the acreage-dependent costs can be increased by the total acres treated to estimate the anticipated costs. Although not evaluated in this cost analysis, it is anticipated that greater economies of scale can be obtained from the fixed cost elements of this treatment by increasing the area treated to equal the available area typically encountered at a CDF. This method of determining costs will likely become increasingly inaccurate if the treated acreage cannot be planted and maintained adequately with the assumed equipment (e.g., irrigation, tilling, and planting).

3.2 Conclusions

Estimated costs for the 1-acre plot remediating a total volume of 1,613 yds^3 of dredged material are approximately \$47,227 and \$44,280 for corn and willow treatments, respectively. Tables 3-1 and 3-2 break down these costs into categories. Costs presented in this report are order-of-magnitude estimates as defined by the American Association of Cost Engineers, with an expected accuracy within +50% and –30%.

3.3 Issues and Assumptions

3.3.1 Site Size and Characteristics

Costs have been provided for a plot that is 1 acre in size or 1,613 yds^3. It is intended that this cost can be adjusted to fit the CDF remediation project being considered by scaling it relative to the actual acreage being remediated. This method of estimating costs for the specific project is only applicable for a project that is a similar magnitude. That is, the project being considered should be of a size at which the equipment used to estimate costs for grading, tilling and irrigating can practically be used. Cost differences may result from changing the methods of grading, tilling and irrigating.

Table 3-1. **Cost Breakdown for Two-Year Treatment using Corn**

Purchased Equipment Costs	QTY	Unit	Unit Cost	Extension
Consumables and Supplies	1	Lump	$500.00	$500.00
Hose Reel Traveling Sprinkler (2)	1	Lump	$8,895.00	$8,895.00
Soil Test Kit (NPK)	1	Lump	$320.00	$320.00
		Equipment Subtotal (EQ):		***$9,715.00***
Taxes (5% of EQ)	1	Lump	$485.75	$485.75
Freight (4% of EQ)	1	Lump	$388.60	$388.60
	Total Purchased Equipment Cost (PEC):			***$10,589.35***
Direct Installation Costs	**QTY**	**Unit**	**Unit Cost**	**Extension**
Mobilization	1	Lump	$170.00	$170.00
Medium Brush with Average Grub and some Trees, Clearing	1	Acre	$624.74	$624.74
Rough Grading, D4 Dozer	8	Hr	$104.80	$838.40
Soil Tilling, D4 Dozer with Tiller Attachment	4	Hr	$81.72	$326.88
	Total Direct Installation Cost (DI):			***$1,960.01***
	TOTAL DIRECT COST (DC) [PEC + DI] :			**$12,549.36**
Indirect Costs	**QTY**	**Unit**	**Unit Cost**	**Extension**
Engineering	1	Lump	$2,000.00	$2,000.00
Construction Oversight (25% DI)	1	Lump	$490.00	$490.00
Permits (1% DC)	1	Lump	$125.49	$125.49
Bonds (1.5% DC)	1	Lump	$188.24	$188.24
Profit and Overhead (8% DC)	1	Lump	$1,003.95	$1,003.95
Contingencies (5% DC)	1	Lump	$627.47	$627.47
		Total Indirect Cost (IC):		***$4,435.15***
	TOTAL CAPITAL INVESTMENT (TCI) [DC + IC]:			**$16,984.51**
Direct Annual Operating Costs	**QTY**	**Unit**	**Unit Cost**	**Extension**
Sampling Event (Analytical Costs) (3)		1	Annual	$1,680.00
Sampling (Labor)	4	Hr	$60.00	$240.00
Irrigation (Labor)	56	Hr	$20.00	$1,120.00
Fuel	1	Season	$500.00	$500.00
Equipment Delivery (4)	1	Season	$2,200.00	$2,200.00
First Corn Planting (Tractor with Spreader and Drill)		1	Day	$450.00
Corn and Fertilizer (5)	1	Acre	$1,900.00	$1,900.00
First Corn Planting (Labor) (6)	8	Hr	$20.00	$160.00
Incorporate 1st Corn (Tractor with Plow and Disk)	1	Day	$450.00	$450.00
Second Corn Planting (Tractor with Spreader and Drill)		1	Day	$450.00
Corn Seed and Fertilizer (5)	1	Acre	$1,900.00	$1,900.00
Second Corn Tilling and Planting (Labor) (7)		16	Hr	$20.00
Incorporate 2nd Corn (Tractor with Plow and Disk)	1	Day	$450.00	$450.00
Winter Clover Planting (Tractor with Drill)		1	Day	$300.00
Winter Clover Tilling and Planting (Labor) (7)		16	Hr	$20.00
Clover Seed (8)	1	Acre	$10.00	$10.00
	Total Direct Annual Operating Cost (DAC):			***$12,450.00***
	TOTAL 2-YEAR DIRECT OPERATING COST (DOC) [DAC X 2]:			**$24,900.00**

Table 3-1 (Con't)

Indirect Annual Operating Costs	QTY	Unit	Unit Cost	Extension
Profit and Overhead (8% of DOC)	1	Lump	$1,992.00	$1,992.00
Administrative Charges (2% TCI)	1	Lump	$339.69	$339.69
Property Taxes (1% TCI)	1	Lump	$169.85	$169.85
Insurance (1% TCI)	1	Lump	$169.85	$169.85
			Total Indirect Annual Operating Cost (IAC):	***$2,671.38***

TOTAL 2-YEAR INDIRECT OPERATING COST (IOC) [IAC X 2]:	**$5,342.76**
TOTAL OPERATING COST (TOC) [DOC + IOC]:	**$30,242.76**
TOTAL COST (TCI + TOC):	**$47,227.27**

Notes:
(1) Costs are considered to be order-of-magnitude estimates with an expected accuracy within 50% above and 30% below the actual cost.
(2) Includes hose and booster pump. Booster pump is required if excessive relief exists between lake level and sprinkler head.
(3) Four composite samples per acre analyzed for DRO, PAH and PCB
(4) Delivery of seed drill is estimated to be $700 for each dilivery. Seed drill must be hoisted onto flat bed due to roadway width restrictions.
(5) Seed requirement is 440,000 seeds/ac. There are approximately 23,000 seeds per bag so 20 bags of corn seed would be required. A bag of seed corn costs approximately $90/bag
(6) Assumes that corn can be planted in one day.
(7) Assumes that plowing and disking can be completed in one day. Assumes corn/clover can be planted in one day.
(8) Assumes clover planted at a rate of 6 lbs/ac.

Table 3-2. Cost Breakdown for Two-Year Treatment using Willow

Purchased Equipment Costs	QTY	Unit	Unit Cost	Extension
Consumables and Supplies	1	Lump	$500.00	$500.00
18-Inch Sandbar Willow Cuttings [(2)]	1	Acre Coverage	$10,585.08	$10,585.08
Hose Reel Traveling Sprinkler [(3)]	1	Lump	$8,895.00	$8,895.00
		Equipment Subtotal (EQ):		***$19,980.08***
Taxes (5% of EQ)	1	Lump	$999.00	$999.00
Freight (4% of EQ)	1	Lump	$799.20	$799.20
		Total Purchased Equipment Cost (PEC):		***$21,778.29***
Direct Installation Costs	**QTY**	**Unit**	**Unit Cost**	**Extension**
Mobilization	1	Rental Unit	$170.00	$170.00
Medium Brush with Average Grub and some Trees, Clearing	1	Acre	$624.74	$624.74
Rough Grading, D4 Dozer	8	Hr	$104.80	$838.40
Soil Tilling, D4 Dozer with Tiller Attachment	4	Hr	$81.72	$326.88
Equipment Delivery	1	Season	$200.00	$200.00
Fertilizer Spreader	1	Day	$150.00	$150.00
Fertilizer [(4)]	1	Acre	$100.00	$100.00
Tree Planting (Tractor with Planter and Spreader)		1	Planting	$1,350.00
Tree Planting (Labor) [(5)]	80	Hr	$20.00	$1,600.00
		Total Direct Installation Cost (DI):		***$5,360.01***
		TOTAL DIRECT COST (DC) [PEC + DI]:		**$27,138.30**
Indirect Costs	**QTY**	**Unit**	**Unit Cost**	**Extension**
Engineering	1	Lump	$2,000.00	$2,000.00
Construction Oversight (25% DI)	1	Lump	$1,340.00	$1,340.00
Permits (1% DC)	1	Lump	$271.38	$271.38
Bonds (1.5% DC)	1	Lump	$407.07	$407.07
Profit and Overhead (8% DC)	1	Lump	$2,171.06	$2,171.06
Contingencies (5% DC)	1	Lump	$1,356.91	$1,356.91
		Total Indirect Cost (IC):		***$7,546.44***
		TOTAL CAPITAL INVESTMENT (TCI) [DC + IC]:		**$34,684.74**
Direct Annual Operating Costs	**QTY**	**Unit**	**Unit Cost**	**Extension**
Sampling Event (Analytical Costs) [(6)]	1	Annual	$1,080.00	$1,080.00
Sampling (Labor)	4	Hr	$60.00	$240.00
Irrigation (Labor)	56	Hr	$20.00	$1,120.00
Fuel	1	Season	$500.00	$500.00
		Total Direct Annual Operating Cost (DAC):		***$2,940.00***
		TOTAL 2-YEAR DIRECT OPERATING COST (DOC) [DAC X 2]:		**$5,880.00**
Indirect Annual Operating Costs	**QTY**	**Unit**	**Unit Cost**	**Extension**
Profit and Overhead (8% of DOC)	1	Lump	$470.40	$470.40
Administrative Charges (2% TCI)	1	Lump	$693.69	$693.69
Property Taxes (1% TCI)	1	Lump	$346.85	$346.85
Insurance (1% TCI)	1	Lump	$346.85	$346.85
		Total Indirect Annual Operating Cost (IAC):		$1,857.79

Table 3-2 (Con't)

TOTAL 2-YEAR INDIRECT OPERATING COST (IOC) [IAC X 2]:	$3,715.58
TOTAL OPERATING COST (TOC) [DOC + IOC]:	$9,595.58
TOTAL COST (TCI + TOC):	$44,280.31

Notes:
(1) Costs are considered to be order-of-magnitude estimates with an expected accuracy within 50% above and 30% below the actual cost.
(2) 39,204 cuttings at $0.27 per cutting
(3) Includes hose and booster pump. Booster pump is required if excessive relief exists between lake level and sprinkler head.
(4) 460 lbs/ac of 13-13-13.
(5) Two laborers for one 40 hour week.
(6) Four composite samples per acre analyzed for DRO, PAH and PCB

It is also assumed that the condition of the site is such that it can be cleared and graded in the time and with the equipment specified in the cost estimate. Additionally, it has been assumed that debris (concrete, metal, etc.) can be removed by hand.

3.3.2 System Design and Performance Factors

It is assumed that drainage and run-off requirements will require minimal consideration for implementation. Design considerations are assumed to be limited to plot layout, irrigation coverage, and coordination of equipment, mobilization, and demobilization.

3.3.3 System Operating Requirements

It is assumed that the area will be initially graded and tilled by trained equipment operators with oversight. Ongoing tilling and planting is assumed to be conducted by general laborers with minimal oversight. Technician labor will be limited to sampling for performance demonstration.

3.3.4 Financial Assumptions

All costs are presented in 2003 U.S. dollars without accounting for interest rates, inflation or the time value of money.

3.4 Basis of Economic Analysis

The cost analysis was prepared by breaking down the overall costs into the following categories:

- Purchased equipment costs
- Direct installation costs
- Indirect costs
- Direct annual operating costs
- Indirect annual operating costs

These cost factors are examined below.

3.4.1 Purchased Equipment Costs

Equipment costs are provided for frequently used equipment where rental cost would likely exceed the purchase cost. Specifically, costs are provided for a hose reel sprinkler system. The hose reel system is a self-propelled sprinkler that crosses the planted area at predetermined transects. The hose reel is not a permanent system and can be operated with minimal labor. For the corn treatment, it is anticipated that the nitrogen/phosphorus/potassium ratio (N-P-K) will be monitored frequently to optimize plant growth. An equipment vendor cost was obtained for a kit that allows for in-field measurements of N-P-K.

3.4.2 Direct Installation Costs

For the corn treatment, direct installation costs include equipment mobilization, medium brush clearing with some tree removal, rough grading, and tilling in preparation for planting. A combination of equipment rental costs and RSMeans cost data were used to estimate these costs.

For the willow treatment, in addition to costs for rough grading and tilling, costs have been provided for fertilizing and tree planting. Fertilizer would be applied using a spreader mounted on a conventional tractor. Tree planting would be accomplished using mechanical tree planter pulled behind a conventional tractor. Planting for a one-acre area is assumed to take one week. Ten percent of the planted area is assumed to be left without trees to accommodate transects for the hose reel sprinkler. Assuming the trees are planted on one-foot centers results in a total of 39,200 trees planted per acre.

3.4.3 *Indirect Costs*

Indirect costs include engineering, construction oversight, permits, bonds, profits and overhead and contingencies. These costs are estimated as percentages of direct costs and direct installation costs.

3.4.4 *Direct Annual Operating Costs*

For the corn treatment, direct annual operating costs include equipment rental, services, and materials required for tilling, planting and irrigation. Rental equipment and analytical services have been estimated based on vendor-provided estimates. Material costs, including seed and fertilizer, were estimated based on various sources of information including the budgetary numbers provide on the University of Tennessee's Extension Services web site. Values for rental equipment and materials were conservatively rounded for purposes of this cost estimate.

Corn will be planted using a seed drill. Fertilizer application is assumed to be accomplished using a spreader mounted on a three-point hitch. Daily rates for the tractor, plow, disk, spreader, and planter are $150/day each. Efforts to estimate delivery costs revealed that load width restrictions are imposed on roadways used to access the Jones Island CDF. As a result, additional fees would be incurred to pick up and load the drill for transport to the CDF. These costs are assumed to be appropriate for the general case because CDFs are frequently located in urban areas that may also have width restrictions associated with their roadways. Additionally, it is assumed that soil preparation (including corn incorporation using a plow and a disk) and planting for a one-acre area can be accomplished in two days. To achieve the high and low moisture levels suggested by the USACE, irrigation is assumed to be conducted every other week during the growing season. During the weeks with irrigation activity, watering would occur every other day. Sampling for constituents of concern is assumed to include collection of four composite samples per acre. One sampling round will occur a the beginning of the treatment and one after the completion of the second growing season. Samples will be analyzed for DRO, PAH and PCB.

For the willow treatment, direct annual operating costs are limited to irrigation and sampling. The same irrigation and sampling assumptions were used for the willow treatment and corn treatment.

3.4.5 *Indirect Annual Operating Costs*

Indirect annual operating costs include percentage-based estimates of profit and overhead, administrative charges, property taxes, and insurance. Profits and overhead are estimated as a percentage of direct operating costs. Administrative charges, property taxes, and insurance are estimated as percentages of total capital investment.

3.5 Summary of Economic Analysis

The distinguishing factor between the treatment alternatives is the difference between direct operating costs and direct installation costs. Direct installation costs for the corn treatment are small compared to direct operating costs. The inverse is true for the willow treatment. Despite this observed difference, the costs per ton are comparable for the corn and willow treatments: $20.91 and $19.74, respectively. This is largely due to a two year operating assumption. For treatment periods extending beyond two years, costs for the corn treatment would continue to increase at a significant rate, whereas operating costs for the willow treatment increase more modestly. In this case, the willow treatment would likely be the more economical alternative. If irrigation was deemed unnecessary (a realistic possibility), costs for either treatment would be reduced by about 30%.

SECTION 4
TREATMENT EFFECTIVENESS

This section describes the effectiveness of the plant- and microbe-based treatments in reducing concentrations of PAHs, PCBs and DRO in dredged materials during a field-scale demonstration of phytoremediation technology at the Jones Island CDF in Milwaukee Harbor, Wisconsin. Information provided in this section includes: (1) site conditions prior to treatment, (2) technology implementation and monitoring, (3) project objectives, including the methods implemented to achieve these objectives, and (4) results and performance, including system reliability and process residuals.

4.1 Background

The U.S. Army Corps of Engineers is tasked with maintaining approximately 140 navigation projects around the Great Lakes. These navigation projects include harbors and channels for commercial and recreational navigation users. Due to the migration of sediments, periodic dredging is required to maintain both commercial and recreational navigable waterways. USACE dredges approximately 3 to 5 million yd^3 (2.3 to 3.8 m^3)of sediments annually from navigable waterways around the Great Lakes (Miller, 1998).

In 1967, the USACE began investigating environmentally sound alternatives to the open water disposal of dredged material. It was during this time that the concept of a confined disposal facility was first conceived and implemented. As of 1998, there were a total of 45 CDFs in the Great Lakes region (Miller, 1998). Of these 45 CDFs, 28 remain operational and 17 are full. Six of the 28 operational CDFs are now nearing design capacity (i.e., 85% full). Because the construction of replacement CDFs is cost-prohibitive, USACE policy now encourages the development of beneficial uses for dredged material.

Many of the Great Lakes areas of concern contain sediments that have quantifiable amounts of PAHs, PCBs, and metals. Typically the concentration of these contaminants is low (barely exceeding solid waste criteria), but high enough to restrict management options. Unfortunately, as with other high volume/low concentration wastes, disposal alternatives are extremely limited (Bowman, 1999).

The Jones Island CDF has received dredgings from the maintenance of surrounding waterways for nearly 30 years. The objective of the field demonstration was to evaluate the potential of four different treatment schemes to "manufacture" a product suitable for beneficial use in the marketplace. The long term goal of the site owner and other stakeholders is to create a system that reduces the material inventory and prolongs the service life of this and other CDFs.

4.2 Project Description

4.2.1 Physical Setting

The 44-acre (17.6-hectare) Jones Island CDF was constructed in 1975 and is of the "in-water" construction type, meaning it was built by reclaiming a portion of Lake Michigan through the installation of breakwaters and dikes. The CDF serves as a disposal facility for maintenance dredged material that is unsuitable for open-lake disposal from both Milwaukee Harbor and Port Washington Harbor, located 25 mi (40 km) north of Milwaukee. The design capacity of the Jones Island CDF is 1.6 million yd^3 (1.2 million m^3). Until recently, annual maintenance dredging quantities typically ranged from 50,000 to 95,000 yd^3 (38,000 to 73,000 m^3). Completion of a storm-water interceptor system in Milwaukee in 1994 reduced annual dredged quantities to around 25,000 yd^3 (19,000 m^3). The remaining capacity is 425,000 yd^3 (325,000 m^3), and it is expected that the CDF will be filled in 20 years (Myers, 1999).

Water enters the Jones Island CDF primarily through three mechanisms:

1. Rainfall
2. Water associated with the dredged sediments deposited in the CDF
3. Groundwater recharge from the west

The sides of the CDF slope inward generally toward a point north of center where a sizable pond has developed. After construction of the CDF, a grout "mattress" was injected along the north dock wall, and bentonite slurry was injected along the northeast and southeast walls. As a result, all water entering CDF boundaries is retained within or atop the dredged material and eventually lost through evaporation.

Approximately one-half of the CDF's areal extent has a depth to the water table equal to or less than 5 ft (1.5 m), which is to say 5 ft (1.5 m) above the low reference datum (LRD) of 576.8 ft (175.8 m) above mean sea level. Information on the nature and extent of seasonal or episodic water table variations is not available. The test site was located near the eastern tip of the CDF where the surface ranged from 4.4 to 7.3 ft (1.3 to 2.2 m) above the LRD.

4.2.2 Site Characterization

A site-wide characterization of dredged materials in the 0 ft - 4 ft (0 m - 1.2 m) depth interval at the Jones Island CDF was completed during September 2000. The purpose of the study was to determine the concentration of PAHs, PCBs (aroclors), DRO, and various agricultural parameters in surface and near surface soils throughout the CDF in order to help select a suitable borrow area of test materials. Sampling locations were identified using a 100 ft x 100 ft (30 m x 30 m) grid overlaying surface topography that is greater than 5 ft (1.5 m) above the LRD. The grid produced 80 potential locations of which 26 were ultimately sampled. Samples were drawn from three different intervals at each location. These depths were 0 ft - 1 ft (0 m - 0.3 m), 1 ft - 2 ft (0.3 m - 0.6 m), and 2 ft - 4 ft (0.6 m - 1.2 m).

Dredged materials encountered during the investigation generally consisted of brown to black silt, with plant rootlets and trace shell material. Wood debris was encountered in samples within and near the portion of the CDF previously used for the biomound study. Some apparent waste (e.g. slag-like materials) was identified in several borings located in the northern and eastern portions of the site.

The analytical data indicate that the soil from the 0 to 1 ft (0 to 0.3 m) interval at the GP-17 sampling location had concentrations similar to the material used by the ERDC in its greenhouse study (section 4.2.3). The total concentration of PAHs and PCBs in the collect soil was 89 mg/kg and 2.7 mg/kg, respectively. Since it was desirable to use material with similar characteristics during the field test, the material around GP-17 was selected as the borrow area (Figure 4-1).

4.2.3 Treatment Options

Four treatments consisting of three plant-based (corn, willow, natural vegetation) and one microbe-based (unplanted) were evaluated during the CDF demonstration. Treatment options were selected through a combination of greenhouse testing, prior field experience, and plant surveys.

In 2000, the ERDC conducted a series of greenhouse trials to evaluate the ability of different plant varieties to reduce the level of PAHs and PCBs in dredged materials collected from the Jones Island CDF. Prior to the trials, the ERDC performed an extensive literature search for plants that showed an ability to treat PAHs and PCBs and could grow well in Milwaukee's climate during the spring and summer months. A number of candidate plants were identified and tested in combination with different soil amendments.

Results show the best reductions were achieved with a fast maturing, medium-height corn hybrid. On unamended dredged material, the corn hybrid reduced the concentration of PAHs and PCBs by 78% and 64%, respectively.

During a 1998 USACE biomound study at Jones Island, a thick vegetative cover developed on the biomounds during a period of relative inactivity. The intensity of the plant cover indicated the existence of a large seed bank in the surface layer of CDF material and the potential of the material to grow and sustain plant life without a great deal of attention. It was later surmised that the vegetation might also be capable of reducing contaminant levels via phytoremediation.

In spring 2001 the ERDC conducted a brief floristic survey of the Jones Island CDF to identify the types of natural vegetation that might develop during the field study. The ERDC reported that the CDF supports vigorous native annual and perennial vegetation during the growing season, and identified 85 species of vascular plants. In the older areas of the CDF, which includes GP-17, the site of the test material borrow area, the dominant vegetation was *Phalaris arundinacea* (Reed Canary Grass), *Salix interior* (Sandbar Willow), and *Urtica procera* (Tall Nettle). The sandbar willow, also known as coyote willow, was associated previously with areas of the CDF exhibiting some of the lowest pollutant concentrations reported from the 2000 characterization study.

The fourth treatment variation selected consisted of tilling and weed control. Weed control was maintained through the use of herbicide (Roundup®).

4.2.4 Treatment Plots

The experimental approach for this demonstration was based, in part, on the design recommendations made by in the July 1999, Field Study Protocol, Phytoremediation of Petroleum in Soil produced by the RTDF Phytoremediation Action Team. This protocol was intended to promote uniformity in test conditions and enhance comparability of results between demonstrations of this technology. One of the key elements described in the RTDF protocol is the use of a replicate-block configuration to evaluate treatments. In this demonstration, the four different treatments were evaluated in four replicate test plots. Each test plot consisted of the four different treatments.

The test plots were configured such that the end of one test plot was immediately adjacent to the beginning of the next test plot. The test plots were located in an area of higher elevation on the CDF away from the pond. (Figure 4-1). In general, the area gently slopes toward the pond and away from the CDF dikes. Prior to the construction of the test plots, the area was cleared of all vegetation and leveled. Debris (concrete, metal, etc) that could damage equipment was removed from the test site.

The test plots were constructed with the overall dimensions of 60 ft W x 23 ft L (18 m x 7 m). Each test plot was divided into four treatment cells each measuring 12 ft W x 20 ft L (4 m x 6 m). The cells were constructed with a 2 ft W x 1.5 ft H (0.6 m x 0.45 m) earthen berm, and the entire plot was constructed with a 3 ft W x 1.5 ft H (0.9 m x 0.45 m) berm except on the downslope side. The berms were be covered with black 40 mil heavy-duty polyethylene sheeting to prevent erosion. The material for the berms was obtained from the area surrounding the test plot location. A landscape fabric that maintains hydraulic conductivity with underlying soil was installed to line the floor of each treatment cell to ensure that only the material placed for treatment was sampled. Figure 1-3 illustrates the test plot layout.

4.2.5 Planting

The dredged material used in the test plots was removed from the borrow area to a depth of 1 ft (0.3 m) using a backhoe. The material was passed through a rotary soil screener to remove debris and homogenize the soil reducing it to a uniform aggregate mix. Once ready for use, a front-end loader was used to deposit the dredged material into each treatment cell. Initially, a tractor-mounted rotary tiller was used mix the material within each cell. However, due to heavy rains between the placement of the material in the cell and tilling the material became wet and the tractor-mounted tiller got stuck. Thus, a walk-behind tiller was used to thoroughly blend the dredged material in each treatment cell. A modest slope over the cell length was maintained to provide adequate drainage.

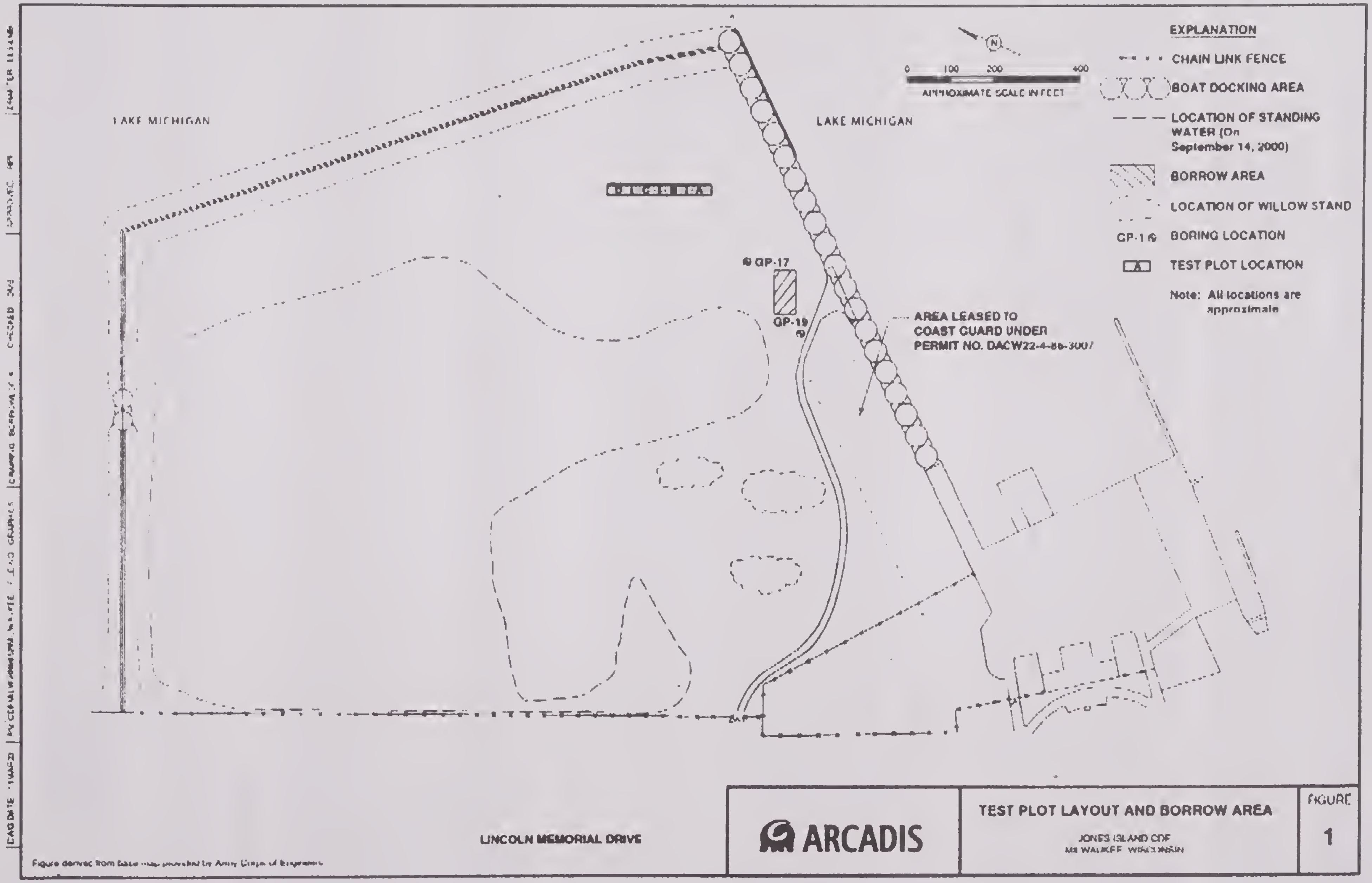

Figure 4-1. Jones Island CDF with Illustrated Test Plot and Borrow Area Locations.

The degree to which these collection, mixing, and placement activities distributed pollutants throughout the soil bed in each treatment cell was unknown and, as a practical matter, could not be known until baseline samples (considered non-critical) were collected and analyzed. Random multiple-aliquot composite sampling was performed to help moderate the effects of potential high and low concentration spots and allow a more accurate reflection of the true concentration of critical analytes.

For the corn treatment, a 45-day growing cycle corn was selected. Two growing cycles were completed during each of the growing season. The corn was seeded as "thick as possible" since root mass is considered essential to treatment performance. The seeds were planted using broadcast spreading techniques.

For the sandbar willows, root mass is also a key part of its treatment capability. As such, a close plant spacing of 1 ft between tree centers was selected. This translates to 209 plants per treatment cell, 836 plants for all four cells. The cuttings (36 in or 0.9 m) were placed in the soil beds down to the underlying landscape fabric, nominally a depth of 1 ft (0.3 m) below soil surface. A total of 340 trees were replanted the beginning of the second growing season (May 2002) due to mortality of the first year trees. The second batch of cuttings were shorter (18 in or 0.45 m) and generally had a wider girth than the original cuttings. Shorter cuttings were used so that a larger portion of the stem would be fixed within the soil. The cuttings were obtained from Segal Ranch, Grandview, WA (509- 840-1045).

4.2.6 Irrigation System

The irrigation system consisted of four 550-gallon polyethylene storage tanks, a trash pump, flexible hose, and polyvinyl chloride (PVC) piping. One storage tank was designated to each test plot. The tanks were situated on earthen mounds constructed at a higher elevation than the treatment cells to allow gravity flow. Irrigation water was pumped from Lake Michigan via a vertical steel pipe placed over the CDF edge and down into the lake surface. The pump outflow traveled through flexible hose and 2-in (5-cm) PVC piping to the storage tanks. The vertical steel pipe was equipped with a ball-check valve at the bottom to prevent back flushing from the pump and to keep the pump primed. Irrigation water gravity fed from the storage tanks to PVC header pipes on either side of each treatment cell and ultimately to flexible drip hose laid across the soil. Flow was controlled by a series of ball valves on the supply and header pipes. The modest slope of the treatment cells allowed the water to infiltrate the seed/plant bed slowly and thoroughly hydrate the soil.

4.2.7 Plot Maintenance

The irrigation system was used to irrigate the test plots when the tensiometers readings were generally below 30 centibars and/or the plots appeared visibly dry (data not shown). Consideration was also given to the rain forecast when making the determination to irrigate. The test plots were irrigated on 12 occasions in 2001 and 17 occasions in 2002.

Due to the healthy seed bank at the CDF, the willow treatment cells were weeded by hand to reduce competitive growth. In this case, the use of herbicide was not a viable option due to the dense planting of the cuttings and the windy conditions at the site that could spread the herbicide and damage the young trees. Soil attached to the weed roots was removed and returned to the cell.

4.2.8 Monitoring

Data collected during the monitoring program was used to manage the system and evaluate the effectiveness of the treatments. The following conditions were monitored during the demonstration:

- Soil PAH, PCB, DRO and agricultural (Row Crop Test/Complete Test) concentrations prior to planting the first season, also known as baseline (T=0), prior to planting the second growing season (T=1), and after the second growing season (T=2).

- Plant assessments were completed during the second growing season to evaluate percent cover, shoot biomass, and root parameters.
- Tensiometers were installed during the second growing season to measure soil moisture.
- Weather data was gathered from the National Oceanic and Atmospheric Administration (NOAA) station at nearby Mitchell Airfield in Milwaukee.

4.3 Project Objectives

In accordance with *QAPP Requirements for Applied Research Projects* (USEPA, 1998), the technical project objectives of this demonstration are categorized as either primary or non-primary. Critical data evaluated as part of the demonstration support primary objectives, and non-critical data evaluated as part of the demonstration support non-primary objectives.

4.3.1 Primary Project Objective

There was one primary objective:

1. **The primary objective of this SITE demonstration was to determine after two growing seasons whether the planned treatments attained residual contaminant levels, on a dry weight basis, for PAHs, PCBs, and DRO, consistent with requirements suggested by the WDNR for this demonstration.** Management and disposition options for dredged sediments are being studied in a cooperative fashion by government and industry stakeholders in the State of Wisconsin. No promulgated standards exist for the beneficial use of dredged sediments. Therefore, treatment goals for this demonstration were suggested by the WDNR that are derived from the most relevant regulations currently available. Results from the end-of-treatment samples (T=2) were compared to the following criteria:

PAHs. The WDNR has suggested that the most appropriate standards for PAHs are in NR 538, Beneficial Use of Industrial Byproducts. Some of these criteria are very low (e.g., benzo(a)pyrene, 0.0088 mg/kg). As a result, selective ion monitoring (SIM) was employed, were appropriate, in an effort to achieve the lowest possible analytical reporting limits.

PCBs. TSCA regulations under 40 CFR 761.61(a)(4)(i)(A) establish $\leq$1 ppm PCBs as the cleanup level for sediments (referred to as "Bulk PCB remediation waste") in "High occupancy areas." High occupancy areas are defined as any area where occupancy for any person not wearing dermal and respiratory protection is 840 hours or more per year.

DRO. Generic Wisconsin residual clean-up levels (RCLs) for DRO are set forth in NR 720.09(4) of the Wisconsin Administrative Code. The generic DRO RCLs are based on the hydraulic conductivity of soil at the site. For soil that exhibits a hydraulic conductivity greater than 1×10^{-6} cm/second, DRO must be 100 mg/kg or less. For soil that exhibits a conductivity less than 1×10^{-6} cm/second, a clean-up level of 250 mg/kg or less is required. The hydraulic conductivity at the Jones Island CDF site has been estimated at greater than 1×10^{-6} cm/second.

4.3.2 Secondary Project Objectives

There were two secondary objectives:

1. Determine the best performing treatment(s) after two growing seasons. For this project, "best performing" is defined as achieving the lowest residual level, on a dry weight basis, for each of the three critical analytes, PAHs, PCBs, and DRO.

2. Describe qualitatively the root and shoot characteristics of the three plant-based treatments over the course of the demonstration.

4.4 Performance Data

4.4.1 Summary of Results - Primary Objective

Soil samples collected during the final sampling event show mixed results against suggested requirements, with only minor improvements between baseline and final sampling periods. None of the treatments produced final concentrations of total PCBs less than 1 mg/kg established in 40 CFR 761.61(a)(4)(i)(A) for bulk PCB remediation waste in high occupancy areas. None of the treatments produced final DRO concentrations of 100 mg/kg or less established in NR 720.09(4) for soils exhibiting a hydraulic conductivity greater than 1 x 10^{-6} cm/second.

4.4.2 Summary of Results - Secondary Objectives

Soil samples collected during the final sampling event show that the treatments performed quite similarly when evaluated by the Tukey Test, a standard statistical tool designed to make these types of comparisons. Plant suppression was found to have a final DRO concentration significantly lower (α = 0.10) than natural vegetation. No other significant differences were observed between the various treatments within the DRO, PAH, and PCB data sets.

Vegetation growth was assessed two times during 2002 on July 29 and in September. The plant assessments showed vegetation treatments were successfully established. Overall, the shallow depth of the soil in the treatment system probably limited plant growth and root development. The soil depth likely restricted plant nutrient availability and resulted in increased irrigation needs more than would probably be required in a system with a deeper soil profile.

4.5 Discussion

4.5.1 Primary Objective

4.5.1.1 Method

Full soil horizon aliquots were collected and composited onsite. The samples were shipped offsite and analyzed by Analytical Laboratory Services, Inc., Middletown, PA (PAHs), Northeast Analytical Laboratory, Schenectady, NY (PCBs), and En Chem, Green Bay, WI (DRO). Samples were analyzed according to the methods summarized in the project QAPP. Results were reported on a dry weight basis.

A total of 16 final (T=2) composite samples were collected and analyzed for each of the three target analytes. PAH data contain 16 individual compounds per sample. Results were reported with a small number of non-detects (6 of 256), which were set equal to the reporting limit (approximately 0.66 mg/kg). Three aroclors (1242, 1254, and 1260) were determined for each PCB sample. One PCB sample per treatment type was further analyzed for the 209 PCB congeners. No non-detects were reported in either the aroclor or congener data set. The concentration of aroclors was summed to produce a total PCB concentration, likewise for the congener samples. The DRO data set consists of one value per sample result. The value represents hydrocarbons in the range of C_{10} - C_{28}. No non-detects were reported.

For each target analyte (PAHs, PCBs, DRO), the database from the final sampling event contains four composites per target analyte per treatment type (e.g., four PAH corn, four PAH willow, and so on), with the exception of PCB congeners for which there is only one sample per treatment type. The results for PAHs, PCB aroclors, and DRO for each treatment type were averaged and a 90% upper confidence limit (UCL) calculated prior to comparison with project objectives. As described earlier, only one PCB congener sample was analyzed per treatment type.

4.5.1.2 Results

PAHs. In comparison with WDNR NR 538 Category 1 standards, corn, natural vegetation, and willow produced 90% UCL PAH concentrations at or below numerical standards with 7 of 16 compounds; plant suppression, 8 of 16 compounds (Table 4-1). Against less stringent Category 2 standards, corn, natural vegetation, and willow produced 90% UCL PAH concentrations at or below numerical standards with 8 of 16 compounds; plant suppression, 11 of 16 compounds (Table 4-2). A similar evaluation using mean T=0 data, however, shows that most of the results described above had already been achieved (data not shown).
PCBs. None of the treatments produced a final mean concentration of total PCBs below this standard. This holds true for both aroclor and congener-based results (Table 4-3).

DRO. None of the treatments produced a final mean concentration of DRO below the applicable standard (Table 4-3). It is interesting to note that the mean DRO concentration of three treatments was below the 100 mg/kg mark at the project outset (data not shown). A number of possible explanations for the increase in DRO over the course of the field demonstration have been explored, ranging from uniformly higher spike recoveries and obscured chromatographic peak areas to natural variability and even biogenesis of similar molecular weight organic compounds. None of these possibilities provides a complete explanation; however, the occurrence underscores some of the inherent difficulty in using analytical techniques based upon fingerprint identification and quantification. Section 4.6.3 presents additional information on the biogenesis of organic compounds.

Table 4-1. PAH Treatment Results vs. NR 538 Category 1 Standards

PAH Compounds	Standard (mg/kg)	Treatment Means (mg/kg)				90% UCL (mg/kg)			
		Corn	Natural	Supprn	Willow	Corn	Natural	Supprn	Willow
Acenaphthene	900	0.70	0.74	0.54	0.76	0.80	0.88	0.60	0.90
Acenaphthylene	8.8	0.72	0.78	0.63	0.69	0.91	0.96	0.75	0.82
Anthracene	5000	1.9	2.0	1.6	2.0	2.3	2.4	1.7	2.4
Benzo(a)anthracene	0.088	6.5	6.8	5.8	6.8	7.4	7.9	6.0	7.4
Benzo(a)pyrene	0.008	7.9	8.8	7.0	8.4	9.1	10	7.4	9.4
Benzo(b)fluoranthene	0.088	11	13	10	12	13	16	11	14
Benzo(g,h,i)perylene	0.88	4.2	3.0	3.7	3.5	5.3	3.5	4.9	4.8
Benzo(k)fluoranthene	0.88	7.5	8.7	5.4	8.5	9.7	9.7	5.7	11
Chrysene	8.8	8.4	8.8	7.5	8.7	9.6	10	8.0	9.4
Dibenzo(a,h)anthracene	0.0088	1.3	1.0	1.2	1.2	1.4	1.2	1.5	1.5
Fluoranthene	600	17	19	15	17	19	21	1.7	20
Fluorene	600	0.75	0.86	0.64	0.83	0.87	1.1	0.7	0.95
Indeno(1,2,3-cd)pyrene	0.088	3.9	3.2	3.7	3.5	4.4	3.8	4.7	4.5
Naphthalene	600	2.0	2.2	1.5	1.5	2.6	2.9	1.7	1.7
Phenanthrene	0.88	8.8	10	7.5	9.2	10	11	8.1	10
Pyrene	500	12	13	10	13	14	15	11	14

Note: Shaded results are at or below standard

Table 4-2. PAH Treatment Results vs. NR 538 Category 2 Standards

PAH Compounds	Standard (mg/kg)	Treatment Means (mg/kg)				90% UCL (mg/kg)			
		Corn	Natural	Supprn	Willow	Corn	Natural	Supprn	Willow
Acenaphthene	9000	0.70	0.74	0.54	0.76	0.80	0.88	0.60	0.90
Acenaphthylene	88	0.72	0.78	0.63	0.69	0.91	0.96	0.75	0.82
Anthracene	50000	1.9	2.0	1.6	2.0	2.3	2.4	1.7	2.4
Benzo(a)anthracene	0.88	6.5	6.8	5.8	6.8	7.4	7.9	6.0	7.4
Benzo(a)pyrene	0.08	7.9	8.8	7.0	8.4	9.1	10	7.4	9.4
Benzo(b)fluoranthene	0.88	11	13	10	12	13	16	11	14
Benzo(g,h,i)perylene	8.8	4.2	3.0	3.7	3.5	5.3	3.5	4.9	4.8
Benzo(k)fluoranthene	8.8	7.5	8.7	5.4	8.5	9.7	9.7	5.7	11
Chrysene	88	8.4	8.8	7.5	8.7	9.6	10	8.0	9.4
Dibenzo(a,h)anthracene	0.088	1.3	1.0	1.2	1.2	1.4	1.2	1.5	1.5
Fluoranthene	6000	17	19	15	17	19	21	1.7	20
Fluorene	6000	0.75	0.86	0.64	0.83	0.87	1.1	0.7	0.95
Indeno(1,2,3-cd)pyrene	0.88	3.9	3.2	3.7	3.5	4.4	3.8	4.7	4.5
Naphthalene	6000	2.0	2.2	1.5	1.5	2.6	2.9	1.7	1.7
Phenanthrene	8.8	8.8	10	7.5	9.2	10	11	8.1	10
Pyrene	5000	12	13	10	13	14	15	11	14

Note: Shaded results are at or below standard

Table 4-3. PCB and DRO Treatment Results vs. Project Standards

Analytes	Standard (mg/kg)	Treatment Means* (mg/kg)				90% UCL (mg/kg)			
		Corn	Natural	Supprn	Willow	Corn	Natural	Supprn	Willow
PCB Aroclors	<1	4.4	4.8	4.2	4.4	5.0	5.6	4.5	5.0
PCB Congeners	<1	4.1	3.9	3.8	3.6	NA	NA	NA	NA
DRO	100	150	230	110	160	180	280	140	200

Notes:
*PCB Congener results are for a single analysis
NA Not applicable

4.5.2 Secondary Objective #1

4.5.2.1 Method

This evaluation utilizes the soil data described in the primary objective with several exceptions: (1) the results were not averaged, (2) the concentration of individual PAH compounds was summed to produce a total PAH value, and (3) PCB congener data was not used. In addition, the correction for an increase in total organic carbon content was deemed unnecessary and therefore not performed. The correction was originally planned due to concerns (in particular) about dilution from the buildup of corn biomass recycled into test material after each crop cycle. Between T=0 and T=2, the TOC content of soils in corn-planted cells actually dropped (4.3 to 4.1%). The other treatments had similar changes: natural vegetation declined from 4.1 to 4.0%; plant suppression increased from 4.1 to 4.5%; and willow did not change (4.1%).

The final composite-sample database contains four composites per target analyte per treatment type.

4.5.2.2 Results

Soil samples collected during the final sampling event show that the treatments performed quite similarly when evaluated by the Tukey Test, which is a statistical procedure designed to determine the best performer through a series of pair-wise comparisons at a specified family-wise level of confidence (in this case, $\alpha = 0.10$. The test is described in more detail in Appendix A. Plant suppression was found to have a final DRO concentration significantly lower than natural vegetation. No other significant differences were observed between the various treatments within the DRO, PAH, and PCB data sets (calculation not shown).

4.5.3 Secondary Objective #2

The full report on plant assessment work is provided as Appendix B. A summary of the methods and results is presented in the following subsections.

4.5.3.1 Method

The plant assessment procedure involved selecting three random points within each vegetation treatment plot. The sampling points were at least 1 meter from the edge of the plot to allow for border effects. A 0.5 meter by 0.5 meter sampling frame was place at each sampling point. The following parameters were estimated.

Percentage cover: Percentage vegetation cover was estimated within the sampling frame. A list was made of all species occurring with the frame. The coverage of each species was visually estimated. The percentage of bare ground also was estimated. The percentage cover analysis was especially important for the natural vegetation treatment to document plant species composition following natural colonization of the plot.

Plant height: Plant height was measured as the height of the tallest plants within the sampling frame.

Above-ground biomass. Shoot biomass is the amount of dry plant material produced in grams per square meter. Vegetation within the area covered by the sample frame was clipped down to the ground surface, placed into plastic bags, shipped a central processing location, dried in an oven, and weighed. Vegetation leaning outside the frame was not included. Sandbar willows were not harvested for biomass. Willow trees that occurred within each sample frame were measured for stem diameter and plant height. Six to nine willow trees were measured from each plot.

Root parameters. Root parameters include root mass, total root length, root surface area, average root diameter, and root length density. Within each quadrat, one full profile core sample was collected using a 78 mm diameter coring device. Each soil core was sampled to the depth of the treatment cell where the synthetic liner was encountered. In the laboratory, soil cores were processed by cleaning the soil from roots using a series of water washes. The cleaned roots were stained with methyl violet, spread on transparency sheets, and scanned using a flatbed scanner. Estimates were obtained from total root length, root surface area, average root diameter, and root length density. Scanned roots were spread for drying to estimate root mass in each sample.

4.5.3.2 Results

Digital photographs were taken of each plot at the two sampling times. Both sets of photographs show good canopy development in corn and natural vegetation plots. The willow plots show good plant survival but rather limited growth of trees during this second growing season. Significant efforts were made to control volunteer vegetation; however, the cycles of weed growth followed by control measures may affect treatment comparisons. This observation is common in many phytoremediation trials. Volunteer vegetation in the plant suppression plots and in the willow plots was well controlled at the time of the second plant assessment event.

The corn treatments were beginning to tassel at the time of the plant assessments. This suggests corn biomass production probably reached close to its maximum potential for each of the corn crops. The stature of the corn plants was quite short indicating that corn growth may have been much less than is usually observed in optimal corn growing conditions. The limited corn growth may be either due to the varieties of corn that were used or due to growth limiting conditions at the site. One important growth limiting condition was the shallow soil depth (about 15 cm) of the treated soil.

Percentage cover was almost 100% in the corn plots for each crop. Plant height was similar for both crops at 74 cm. Above-ground biomass was similar for both plantings. However root mass was significantly greater in the first planting compared to the second planting. Since the plant rooting depth was limited by the depth of the treated soil, the root mass estimate for the corn plots may be a good estimate of total corn root mass. The ratio of root mass to aboveground biomass is only about 10% for the corn plots. A higher ratio of root

mass to aboveground biomass would usually be expected. This further indicates that limited soil volume may have limited corn growth potential.

Both the corn and natural vegetation treatments showed nearly 100% vegetation cover while the willow plots has less than 10% vegetation cover. This is a clear indication that the willow plantings have not fully developed by the end of the second growing season. Root growth in the willow plots was also limited compared to the other treatments. This should be taken into consideration in interpreting the results of this trial. The similarity of average root diameter in the willow plots compared to the other treatments also indicates that a limited number of tree roots were recovered in the sampled soil cores. Willow roots would usually be expected to have higher root diameter then the other herbaceous species such as the grasses found in this study. The natural vegetation treatment had significantly higher root production than either the corn or willow treatments. These results indicate that natural recovery of vegetation produced good root growth under a low management treatment scheme.

Corn plots produced higher above-ground biomass than the natural vegetation plots. Although root parameters for the total corn data were higher than for the natural vegetation treatment, most of these differences were not statistically significant..These results show, however, that an intensively managed cropping system such as several corn plantings could produce greater root growth than a less intensively managed system. System performance, management considerations, and economics would determine if an intensively managed plant system is warranted compared to a minimally managed plant system. During the limited term of this trial, the corn and natural vegetation treatments clearly produced greater root growth than the willow treatment. A longer term treatment system would be needed for effective assessment of the willow treatment.

Correlation coefficients between each pair of plant assessment parameters were calculated within each of the vegetation treatments. Above-ground plant growth, either measured as plant height or as above-ground biomass production was not correlated with root growth parameters. This suggests that under the conditions of this trial, it was necessary to evaluate plant root growth separately from above-ground growth to understand the extent of plant root development. Root mass, root length, root surface area, and root length density were all highly correlated. This observation held for each treatment. The association of root parameter estimates suggests that an assessment of root mass may provide as a reasonable estimate of plant density. Root mass is easier to measure than root length and density. This observation may be helpful in planning future trials.

Assessment of the vegetation composition of the natural vegetation treatment was important for determining which plant species occupied the site. The plant community at represents an early stage of ecological success. Composition of the plant community would be expected to change with the length of time the plots are allowed to grow. Twenty-four total plant species from 12 plant families were identified in the natural vegetation plots. Nine of the species were members of the Asteraceae or sunflower family. The dominant species in all plots was *Phalaris arundinacea* L. or reed canary grass. The proportion of bare ground in the plots was limited to an overall average of 5%. Only plant species present within the sample quadrats at the time of the assessment in late September were recorded in this survey. Additional species were present in other part of the plots and at other times during the growing season. These results show the treated soil can support diverse plant communities from seeds naturally present at the CDF.

4.5.4 QA Review of Critical Sampling and Analysis Data

A review of the critical sample data and associated QC analyses was performed to determine whether the data collected were of adequate quality to provide proper evaluation of the project's technical objectives. The critical data consisted of the DRO, PAH and PCB analyses of samples from the test plots collected during the final post-treatment event. The results of the measurements designed to assess the data quality objectives are summarized below, along with a discussion of the impact of data quality on achieving the project's technical objectives.

<u>Accuracy:</u> Select samples from the test plots were spiked, analyzed and evaluated for accuracy based upon analyte recoveries. Additionally, spiked blanks or LCSs were also analyzed. Results summarized in Table 4-4 indicate that all average recoveries were within specified control limits for all critical analyses. Several PAHs had recoveries outside QA objectives in one or more of the individual spikes analyzed; however, when

spikes were re-extracted and re-analyzed at a higher concentration more appropriate to the native sample concentration, all recoveries were within control limits. Average recoveries of all 16 PAHs in the low and high spikes were the same. As a further evaluation of potential bias, a continuing calibration check standard, analyzed at least daily, was prepared using a second source standard and used to verify the accuracy of the initial calibration. These QC measurements indicated that sample analysis was performed in the absence of significant bias and results can be considered to have met accuracy objectives.

Precision: For this project, precision was assessed by the analysis of spiked duplicates as well as the collection of homogenization replicates. All DRO and PCB spiked duplicate pairs had relative percent differences (RPD) within specified criteria. Six PAH compounds had RPD values that exceeded the 35% RPD criteria. Results for analyte precision, based on the RPD between spiked duplicate pairs, LCS/LCSD RPD values where appropriate and the homogenization replicates are summarized in Table 4-5. One of the two DRO homogenization replicates had RPD values outside the 35% guidelines and two of 32 RPD values for the low level PAH spikes analyzed were above 35% but re-extraction and re-analysis at a higher concentration resulted in all RPD values within limits. Overall, precision data indicated representative samples were collected and analyzed.

Table 4-4. Overall Accuracy Summary - Jones Island CDF Critical Sample Data

Parameter	Avg. Spiked Recovery	Recovery Range	# Spiked Recoveries OC*	Average LCS Recovery
DRO	72 %	64-79 %	0/2	76 %
PAHs: Low (1)	98.5 %	19-187 %	19/64	88 %
PAHs: High (2)	99 %	69-139 %	0/64	88 %
PCBs	111 %	106-116 %	0/4	101 %

*OC = Number of spiked recoveries for each analyte that was outside control limits, out of the total number of spiked analytes analyzed.
(1) Accuracy data based on spikes performed at a low level relative to native sample concentrations; average spiked recovery based on all 16 compounds for the four spikes analyzed.
(2) Accuracy data based on spikes performed at a level five times higher than the low spike concentration; average spiked recovery based on all 16 compounds for the four spikes analyzed. Note that the LCS was not spiked at an elevated concentration.

Detection limit objectives were met for all samples. DRO and PCB results were all reported at levels more than 10 times above the detection limits (DLs) specified in the QAPP (10 and 0.1 mg/kg, respectively). All PAH compounds had DLs below the specified limits, or were detected at levels above the detection limits specified in the QAPP; for some compounds, these limits would have required the use of SIM analysis (e.g., benzo(a)pyrene and dibenz(a,h)anthracene had DLs of 8 ug/kg; benzo(a)anthracene, benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene had DLs of 80 ug/kg).

Completeness objectives for the project were met.

Comparability expresses the extent to which one data set can be compared to another. To generate comparable results, standard methods that are widely accepted along with strict analytical and field protocols were used. These methods were clearly specified in the QAPP and reviewed before samples or data were collected.

Table 4-5. Overall Precision Summary - Jones Island CDF Critical Sample Data

Parameter	MS/MSD		LCS/LCSD		Homogenization Replicate RPD Range
	RPD Range	# OC*	RPD Range	# OC*	
DRO	21	0/1	9.3	0/1	18-37
PAHs: Low (1)	0-78	6/32	NA	NA	0-45.9
PAHs: High (2)	0-30	0/32	NA	NA	--
PCBs	0-8	0/2	NA	NA	1.1-5.1

*OC = Number of RPD values for each analyte that was outside control limits, out of the total number of RPD values calculated for the spiked duplicate pairs analyzed.
NA: LCSs not analyzed as spiked duplicates
(1) Precision data based on spiked duplicates performed at a low level relative to native sample concentrations; RPD range based on all 16 compounds for the two spiked duplicate pairs analyzed.
(2) Precision data based on spiked duplicates performed at a level five times higher than the low spike concentration; RPD range based on all 16 compounds for the two spiked duplicate pairs analyzed.

Representativeness refers to the degree with which a sample exhibits average properties of the site at the particular time being evaluated. This is achieved by ensuring that collection procedures are appropriate for the matrix and sampling location. An independent QA audit conducted during sampling ensured QAPP approved procedures were being followed. Homogenization replicates, collected and analyzed throughout the project, indicated that samples were well-mixed and representative.

Based upon the review of the data quality indicators as discussed above, it appears the critical data generated during the final sampling and analysis post-treatment event for the Jones Island CDF Dredged Material Reclamation demonstration met QAPP-specified criteria. These data are considered suitable without qualification for use in evaluating the project objectives for the demonstration of the reclamation and remedial process.

4.6 Other Issues Related to this Demonstration

4.6.1 Establishing the Baseline Condition at the Site

Purposeful effort was expended to mix the dredge materials as thoroughly as possible at baseline prior to planting. It was hoped that the 16 treatment cells would be nearly homogeneous with respect to the levels of the contaminants of interest. After baseline primary and field duplicate samples were collected and analyzed, the results were evaluated statistically in order to answer three fundamental questions:

0. Are the contaminants uniformly distributed across the 16 treatment cells at baseline?
1. Do the primary and field duplicate samples tell the same story?
2. Is the mean of a given analyte (PAHs, PCBs, or DRO) essentially the same in the cells of the four types of treatments being tested?

The evaluations arrived at the following conclusions:

3. PAHs and PCBs were uniformly distributed among the treatment cells at T=0, but DRO was not.
4. In terms of means (or medians), there was no significant difference between primary and field duplicate samples for PAHs and DRO. However, there was a significant difference between PCB primary and field duplicate samples.
5. The means for PAHs, PCBs, and DROs were not significantly different among each of the four treatment types.

Details of the statistical evaluations are presented in the companion Technology Evaluation Report.

4.6.2 General Observations

In the summer of 2001, after the establishment of the test plots, management routines were not set up properly, leading to less-than-optimum irrigation schedules and inadequate weeding in the willow and plant suppression plots. Corn did not germinate in the initial planting and was replanted by the ERDC in August, 2001. The only plots that had plant growth for most of the growing season was the natural vegetation and the willow plots (which had significant weed growth). Comparing the total PAH data for T=0 and T=1 (see table 4-6), concentration reduction ranked by treatment was natural vegetation>willow>corn. Natural vegetation and willow plots had the longest period of exposure to plant roots during the 2001 growing season, which is possibly the reason for the greater reduction in PAHs.

Reductions of PAH concentrations in 2002 were ranked natural vegetation>corn>willow, which is consistent with total root mass natural vegetation>corn>willow determined by the plant assessments (see Appendix B). With better weed control in the willow plots during the 2002 growing season, less root mass was produced and PAH reduction ceased.

4.6.3 Potential for Formation of Biogenic Hydrocarbons

Chromatograms from DRO analyses were analyzed to determine likely causes of observed fluctuations and increases in DRO concentrations over the treatment period. Two causes of the observed behavior were deemed likely: biogenic hydrocarbons, and organic carbon decay.

An analysis of chromatograms was completed to determine whether the observed fluctuation of diesel range organic concentrations was due to biogenic hydrocarbon sources. Biogenic hydrocarbons are generated by biological sources such as land plants, phytoplankton, animals, bacteria, and algae (Wang et al, 1999). Plants in particular emit a wide range of hydrocarbons into the atmosphere, the most abundant being isoprene and monoterpenes. Based on a review of the available literature, a potential for the formation of biogenic hydrocarbon exists in treatment cells where corn was planted because decomposition of corn biomass tilled into these cells as a function of the demonstration design could theoretically lead to the formation of biogenic hydrocarbons. These hydrocarbons and their corresponding peaks, called the biogenic cluster, are present in a specific range of the Wisconsin Modified DRO (WDNR, 1995) method and would be expected at around 20 minutes on the chromatographs (Wang et al, 1999).

For this project, DRO chromatograms from the three sampling events were evaluated. These chromatograms show peak integration from 5 to 13 minutes. The Wisconsin Modified DRO method requires a diesel standard be run to establish the DRO range, and states that the DRO range comprises the chromatographic responses falling between the n-decane (C10) to n-octacosane (C28) peaks. A diesel component standard run with this method would typically have the standard peaks ranging from 10.44 minutes to 28.126 minutes. Consistent with the Wisconsin Modified DRO method, the laboratory's standard operating procedure for the DRO method requires the diesel component standard be run to establish the DRO range. The diesel component standard used by the laboratory has a time range of 10 to 28 minutes, however individual GC columns may vary when running the Wisconsin Modified DRO method. In running the standards, the laboratory found their DRO range to be from 5 to 13 minutes. As a result, the DRO peak integration stopped at 13 minutes regardless of whether more peaks were present. The peaks beyond the 13 minutes were considered outside of (i.e. heavier than) the DRO range. Assuming a linear relationship between chromatograms, a biogenic cluster peak observed at 20 minutes in the 10 to 28 minute range corresponds to 8.9 minutes in the 5 to 13 minute range.

A comparison of chromatograms for the Plot C corn cell samples to chromatograms for natural vegetation, plant suppression, and willow samples from Plot C was conducted. The detection of biogenic hydrocarbons would not be expected at the T=0 sampling interval since steps were taken to homogenize the dredged material present in all the test cells and no divergence in DRO would have occurred yet as a result of vegetative differences among test cells. The fingerprints of DRO chromatograms for natural vegetation, plant suppression, and willow samples appear quite comparable.

Table 4-6. Comparison between T=0, 1 & 2 Analyte Data

	Polynuclear Aromatic Hydrocarbons (mg/kg)											
	Corn			Natural Vegetation			Plant Suppression			Willow		
PAH Compounds	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2
Acenaphthene	0.90	0.85	0.70	1.3	1.1	0.74	0.65	0.96	0.54	0.94	0.86	0.76
Acenaphthylene	0.73	0.96	0.72	0.72	1.1	0.78	0.70	0.88	0.63	0.76	0.96	0.69
Anthracene	2.6	1.8	1.9	4.0	2.4	2.0	1.9	2.2	1.6	2.6	1.8	2.0
Benzo(a)anthracene	7.4	7.2	6.5	10	7.9	6.8	6.6	7.6	5.8	8.6	7.0	6.8
Benzo(a)pyrene	9.0	9.2	7.9	12	11	8.8	8.2	9.5	7.0	10	9.2	8.4
Benzo(b)fluoranthene	14	15	11	18	18	13	13	15	10	16	15	12
Benzo(g,h,i)perylene	3.4	3.0	4.2	3.6	3.3	3.0	3.0	3.9	3.7	4.1	2.8	3.5
Benzo(k)fluoranthene	5.6	5.7	7.5	7.6	7.0	8.7	5.7	6.2	5.4	5.6	6.8	8.5
Chrysene	9.2	8.5	8.4	12	9.5	8.8	8.1	8.9	7.5	11	8.3	8.7
Dibenzo(a,h)anthracene	1.1	1.0	1.3	1.2	1.1	1.0	1.0	1.2	1.2	1.4	0.91	1.2
Fluoranthene	16	18	17	22	20	19	14	19	15	18	18	17
Fluorene	1.1	0.98	0.75	1.7	1.3	0.86	0.74	1.1	0.64	1.1	0.98	0.83
Indeno(1,2,3-cd)pyrene	3.7	3.2	3.9	4.0	3.6	3.2	3.2	4.1	3.7	4.4	3.2	3.5
Naphthalene	1.7	1.7	2.0	2.2	1.7	2.2	1.6	1.9	1.5	2.3	1.6	1.5
Phenanthrene	10	8.6	8.8	15	11	10	8.2	10	7.5	12	8.7	9.2
Pyrene	14	12	12	18	14	13	12	13	10	15	12	13
Total PAHs	100	98	94	130	110	100	89	110	74	110	98	97
	PCB Aroclors (mg/kg)											
	Corn			Natural Vegetation			Plant Suppression			Willow		
PCB Aroclors	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2
1242	1.1	1.5	1.4	0.94	1.6	1.6	0.96	1.6	1.4	0.94	1.6	1.5
1254	1.3	1.9	2.0	1.2	2.1	2.2	1.2	1.9	1.9	1.2	2.0	2.0
1260	0.40	0.75	0.93	0.36	1.1	1.1	0.37	0.78	0.88	0.41	0.87	0.94
Total Aroclors	2.8	4.2	4.4	2.5	4.9	4.8	2.5	4.3	4.2	2.5	4.5	4.4
	PCB Congeners (mg/kg)											
	Corn			Natural Vegetation			Plant Suppression			Willow		
	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2
Total Congeners	4.2	3.2	4.1	3.7	4.6	3.9	4.7	3.7	3.8	3.9	3.4	3.6
	Diesel Range Organics (mg/kg)											
	Corn			Natural Vegetation			Plant Suppression			Willow		
	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2	T=0	T=1	T=2
DRO	64	140	150	140	250	230	59	220	110	91	280	160

Note: Results rounded to two significant figures

A comparison of chromatograms for the Plot C corn cell samples to chromatograms for natural vegetation, plant suppression, and willow samples from Plot C was conducted. The detection of biogenic hydrocarbons would not be expected at the T=0 sampling interval since steps were taken to homogenize the dredged material present in all the test cells and no divergence in DRO would have occurred yet as a result of vegetative differences among test cells. The fingerprints of DRO chromatograms for natural vegetation, plant suppression, and willow samples appear quite comparable. Comparison of chromatograms for samples withdrawn from corn test cells to the nearly identical fingerprints associated with the DRO samples from other test cells revealed that numerous individual peaks not found in DRO chromatograms for other test cells are present on the leading edge of the corn test cell DRO chromatogram. This difference in DRO fingerprint is most notably present at the T=1 sample interval. The T=1 sample interval occurred in the spring of 2002 after tilling in one 2001 corn crop and the elapse of the winter season, which potentially provided time for biogenic hydrocarbon formation. Though there is a difference in the DRO fingerprints of corn versus other test cells, the magnitudes of the extra peak areas that distinguish the T=1 corn DRO chromatogram are small relative to the total DRO detected during the analysis suggesting that the impact of any biogenic hydrocarbons that are present on the total DRO concentration for this sample is limited. Though one crop of corn was grown and tilled into the corn test cells during the 2002 growing season, a comparison of the Plot C, T=2 DRO chromatograms does not as clearly support the notion of biogenic hydrocarbon formation as the comparison for T=1. A compilation of chromatograms analyzed for evidence of biogenic hydrocarbons can be found in Appendix C.

Section 5
Other Technology Requirements

5.1 Environmental Regulation Requirements

This demonstration was conducted under the jurisdiction of the WDNR. Similar phytoremediation efforts conducted outside of the state of Wisconsin will likely be subject to alternate federal, state and/or local regulations consistent with the change in jurisdiction. Governing agencies may require permits prior to implementing a phytoremediation technology on dredged material. An air permit issued by the state Air Quality Control Region may be required if air emissions in excess of regulatory criteria, or of toxic concern, are anticipated. If remediation is conducted at a Superfund site, federal agencies, primarily the U.S. EPA, will provide regulatory oversight. Section 2 of this report further discusses the environmental regulations that may apply to this phytoremediation process.

5.2 Personnel Issues

A number of personnel are required to implement this phytoremediation technology with its various stages. The exact number will be largely dependent on the size of the area to be treated. Because this technology lends itself to the remediation of large sites, extensive site preparation with mechanized large equipment and assembly of a large irrigation system may require several individuals (inclusive of contractors). After site setup, labor associated with a phytoremediation system such as the one demonstrated at the Jones Island CDF is limited to tilling, fertilization, replanting and irrigation as needed. These tasks could be accomplished at time critical points by a small group of individuals over a one to three day period. Monitoring and sampling events will likely involve decisions about the need for irrigation and the collection of samples to determine the progress of the remedial effort. Estimated labor requirements for the treatment of an acre to one foot depth are discussed in detail in Section 3 of this report.

For most sites, the personnel protective equipment (PPE) for workers will include steel-toed shoes or boots, safety glasses, hard hats, and chemical resistant gloves. Noise levels would usually not be a concern for an application of this phytoremediation technology. However some equipment used for crop cultivation and vegetative clearing and regrading (i.e. tillers, mowers, chain saws, etc.) could create appreciable noise. Thus, noise levels should be monitored for such equipment to ensure that workers are not exposed to noise levels above the time weighted average of 85 decibels over an 8-hour day. If this level is exceeded and cannot be reduced, workers would be required to wear hearing protection.

5.3 Community Acceptance

Potential hazards to a surrounding community may include exposure to particulate matter that becomes airborne during regrading and tilling operations. VOC air emissions are possible if VOCs are also present in the soil. Particulate air emissions can be controlled by dust suppression measures.

Overall, there are few environmental disturbances associated with phytoremediation. No appreciable noise, beyond that generated by the short term use of agricultural equipment, is anticipated for the majority of the treatment time. A fence may be desirable to keep animals and unauthorized visitors from entering the site.

The Jones Island CDF has become an impromptu wildlife sanctuary that is well recognized by local residents who frequent it for activities such as birdwatching. Should this be the case at other CDFs, remediation efforts may be met with concerns about wildlife habitat destruction.

Section 6
Technology Status

6.1 Previous Experience

6.1.1 USACE Dredging Operations and Environmental Research

For the USACE, this demonstration is part of a continuum of projects under its Dredging Operations and Environmental Research (DOER) program. A compendium of DOER efforts examining dredged material characterization, treatment and beneficial use options is available in the form of Technical Notes, which can be downloaded in PDF format at the following address: http://www.wes.army.mil/el/dots/doer/technote.html.

For more information on DOER activities surrounding this and other similar projects, contact Richard Price. Communication information for Mr. Price is given in section 1.7.

6.1.2 Volatilization Study

One potential pathway of migration from a CDF is volatilization of compounds. Disposal, storage, and treatment operations associated with placement of dredged materials in CDFs can increase the opportunity for emissions. The emission of organic compounds from exposed contaminated dredged materials is known to depend upon a variety of factors related to sediment physical characteristics, contaminant chemical properties, and environmental variables.

To verify previous work in assessing contaminant emission losses from CDFs, a controlled simulation experiment was conducted in the field in October of 1999 with contaminated sediment used in previous laboratory investigations. The field location was the Bayport CDF located in Green Bay, WI. Volatile emissions of PCBs were monitored from a biomound treatment containing one part each of dredged material, wood chips and biosolids. The mound measured 132 ft L (40 m) by 9 ft W (2.7 m) with 5 ft (1.5 m) sloped sides. Sampling was conducted before and immediately after the mounds were turned. Emissions were monitored using a modified flux chamber developed for previous field experiments. The apparatus was designed to form an air tight seal over a fixed surface area of the biomound. Air was passed across the exposed sediment area for 6 hours. The mounds were turned, and then the flux chamber was reapplied immediately.

Air and soil samples were collected pre- and post-turning. Analysis of the soil samples revealed the presence of one aroclor and several congeners in ug/kg concentrations. Comparison of pre- and post-turning results suggest that there was no significant change in soil concentration as a result of the mound turning operation. This observation is corroborated by the air sample analyses, which were reported as non-detect for PCB aroclors and congeners.

For details on this volatilization study, contact Richard Price. Communication information for Mr. Price is given in section 1.7.

6.1.3 Center for By-Products Utilization

In conjunction with the 1998 USACE biomound study mentioned in section 4.2.3, the University of Wisconsin-Milwaukee Center for By-Products Utilization (UWM-CBU) assisted in the effort to find beneficial uses for the treated dredged materials. UWM-CBU identified potential users, and those which could utilize large quantities of treated material include nurseries and associated stock dealers, fertilizer manufacturers, arboretums, botanical gardens, landscapers, golf courses, parks, government agricultural offices, and top soil marketers. The companies targeted were primarily within 30 miles (48 km) of Jones Island or its sister facility in Green

Bay. This was judged to be the maximum distance to cost-effectively transport the treated materials. The companies, which total approximately 200, were identified through Internet searches.

For details concerning the UWM-CBU effort, contact Dave Bowman. Communication information for Mr. Bowman is given in section 1.7.

6.2 Ongoing Studies at Jones Island

The USACE is continuing studies at the Jones Island test site. In June 2003, the ERDC collected samples for evaluation through earthworm bioassays. Earthworm bioassays are a widely recognized tool for evaluating the toxicity of contaminated soils and establishing the bioavailability of the pollutants contained therein. Testing results should be available Fall 2003.

For details on the earthworm bioassays, contact Richard Price. Communication information for Mr. Price is given in section 1.7.

6.3 Scaling Capabilities

The technology developer expects that this phytoremediation technology be scaled up for application to substantial, acre-size footprints at the Jones Island CDF and potentially at other CDFs that exhibit characteristics consistent with its implementation. Much of the design of this phytoremediation approach to the remediation of dredged material has incorporated scale-up as it was developed. For instance, ordinary row crop farming techniques such tilling, fertilization, irrigation, and potentially pest management are readily available in a broad geographic area and are applicable to scale-up during future implementation. Section 3 of this document discusses some of the techniques that will facilitate scale-up in greater detail.

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Appendix A
Tukey Test

Of interest is a comparison of treatment results at time T=2. The statistical hypothesis procedure presented here is designed around making all pairwise comparisons between treatments, with a family-wise error rate of 0.10. These pair-wise comparisons were performed using the Tukey test. Generally, the Tukey test is associated with a one-way analysis of variance where interest lies in making all pairwise comparisons rather than simply assessing whether the main effect is significant.

The Tukey test is designed to maintain the family-wise error rate at some specified level when all possible pairwise comparisons between treatment means are made. For this study, the family-wise error rate will be set to 0.10. Conducting the Tukey test involves the following steps:

1. Let a = the number of treatments.
2. Let r = the number of replicates (composites) per treatment
3. Let x_{ij} represent the value of the i^{th} data point in the j^{th} treatment.
4. Define $\bar{x}_j$ as the mean of j^{th} treatment.
5. Calculate all treatment means. For a fixed j, define $\bar{x}_j = \frac{1}{r}\sum_{i=1}^{r} x_{ij}$
6. For each pair of means, define d_{ij} as the difference between treatment means. Calculate d_{ij} so that the smaller mean is always subtracted from the larger mean. That is, $d_{ij} = (\bar{x}_i - \bar{x}_j)$ should be positive.
7. Calculate the minimum pairwise difference ($\bar{d}_{Tukey}$) between means that must be exceeded to be significant with the Tukey test.
8. Define $\bar{d}_{Tukey} = \frac{q_T\sqrt{MS_{error}}}{\sqrt{r}}$

where,

$$MS_{error}(RCBD) = \frac{\sum_{i=1}^{4}\sum_{j=1}^{4}(X_{ij} - \bar{X}_{.j} - \bar{X}_{i.} - \bar{X}_{..})^2}{(4-1)(4-1)}$$

such that

$$\bar{X}_{.j} = \frac{\sum_{i=1}^{4} X_{ij}}{4}$$

$$\bar{X}_{i.} = \frac{\sum_{j=1}^{4} X_{ij}}{4}$$

$$\overline{X}_{..} = \frac{\sum_{j=1}^{4} X_{.j}}{4}$$

q_T is a value from a **studentized range statistic** table. Values from this table are dependent upon:
a = number of treatments = 4 for this study
df_{error} = degrees of freedom associated with MS_{error} = (a-1)(r-1) = (3) (3) = 9 for this study
Family-wise error rate = 0.10 for this study.

9. Compare each d_{ij} with $\overline{d}_{Tukey}$. If d_{ij} is greater than $\overline{d}_{Tukey}$ then it can be concluded that $\overline{x}_i$ is significantly greater then $\overline{x}_j$.

Appendix B
Plant Assessments

DREDGED MATERIAL RELCAMATION DEMONSTRATION AT THE JONES ISLAND CONFINED DISPOSAL FACILITY MILWAUKEE, WISCONSIN

PLANT ASSESSMENT RESULTS

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March 22, 2003

Executive Summary

Vegetation growth at the Dredge Material Reclamation Demonstration was assessed two times during 2002 on July 29 and September. Vegetation cover, aboveground biomass production, and root growth parameters were evaluated for the first corn planting at the first sampling event and for the second corn planting, the natural revegetation plots, and sandbar willow plots at the second sampling event.

The plant assessments showed vegetation treatments were successfully established. In particular, the natural revegetation treatment showed rapid colonization of the plots resulting in a diverse plant community dominated by *Phalaris arundinacea* (reed canarygrass). Aboveground biomass production and root growth in the natural revegetation plots was superior to a single planting of corn. Two crops of corn, however, produced growth that equaled the natural revegetation plots indicating that an intensively managed plant system may be able to produce higher plant biomass then a low management system. System performance in meeting remediation objectives, management considerations, and economics would determine if increased management is warranted.

The sandbar willow planting produced small trees that did not fully cover the plots by the end of the second growing season. This treatment has establishing well but had not reached its full potential. A longer trial would be needed to evaluate the efficacy of the willow planting.

Overall, the shallow depth of the soil in the treatment system probably limited plant growth and root development. Both corn plantings reached a mean plant height of 74 cm. The soil depth in most of the trial area was about 15 cm (6 inches). The soil depth likely limited plant nutrient availability and resulted in increased irrigation needs than would probably be required in a system with a deeper soil profile.

Correlations among plant assessment parameters showed that aboveground biomass production was not correlated with root growth. Therefore, it is necessary to sample roots to determine the extent of plant root development. In this trial, root mass was highly correlated with root length, root surface area, and root length density indicating that estimation of root mass may be a useful indicator of plant root development in vegetative remediation trials similar to this one.

Introduction and Methods

Vegetation growth was assessed at two times during the 2002 growing season as specified in the Quality Assurance Project Plan for the Dredged Material Reclamation Demonstration at the Jones Island confined disposal facility in Milwaukee Wisconsin. The scope of work for the vegetation assessment (Appendix 1) specifies that vegetative treatments would be evaluated to show the success of establishing treatments and to document root development. The extent of root development is thought to be important for achieving optimal phytoremediation activity.

The four vegetation treatments included corn, sandbar willow, natural revegetation, and a plant suppression treatment. In 2002, corn was planted on June 12 and August 1. The sandbar willow treatments were planted on June 22, 2001. The first vegetation assessment took place on July 29, 2002, 47 days after the first corn planting and just prior to tillage of the corn and replanting. This event is called Time 1. At this event, only the corn plots were sampled for biomass production and root growth. Herbarium specimens were taken at Time 1 from the natural revegetation plots in order to identify plant species. The second plant assessment event took place on September 23, 2002. This event is called Time 2. This was 53 days after the second corn planting. The corn, willow, and natural revegetation treatments were sampled.

The plant assessment procedure involved selecting three random points within each vegetation treatment plot. The sampling points were at least 1 meter from the edge of the plot to allow for border effects. A 0.5 meter by 0.5 meter sampling frame was place at each sampling point. The following parameters were estimated.

Percentage cover: Percentage vegetation cover was estimated within the sampling frame. A list was made of all species occurring with the frame. The coverage of each species was visually estimated. The percentage of bare ground also was estimated. The percentage cover analysis was especially important for the natural revegetation treatment to document plant species composition following natural colonization of the plot.

Plant height: Plant height was measured as the height of the tallest plants within the sampling frame.

Aboveground biomass: Shoot biomass is the amount of dry plant material produced in grams per square meter. Vegetation within the area covered by the sample frame was clipped down to the ground surface, placed into plastic bags, shipped a central processing location, dried in an oven, and weighed. Vegetation leaning outside the frame was not included. Biomass from the corn and natural revegetation plots were estimated by this technique. Sandbar willows were not harvested for biomass. Willow trees that occurred within each sample frame were measured for stem diameter and plant height. Six to nine willow trees were measured from each plot. Stem diameter was measured in two places on each tree. The main stem was measured 15 cm from the ground surface. The largest new branch growing from the original planting stock was measured 10 cm from the branch point.

Root parameters: Root parameters include root mass, total root length, root surface area, average root diameter, and root length density. Within each quadrat, one full profile core sample was collected using a 78 mm diameter coring device. Although the intended depth of the soil to be treated in the trial was 30 cm (12 inches), the actual soil depth in the treatment cells was very close to 15 cm (6 inches). Each soil core was sampled to the depth of the treatment cell where the synthetic liner was encountered. The depth of each soil core was recorded. Soil cores were stored in plastic bags and stored at 4C until processed. In the laboratory, soil cores were processed by cleaning the soil from roots using a series of water washes. Following a final hand cleaning procedure to remove non-root organic matter, clean roots were stained with methyl violet. Stained roots were spread on transparency sheets and scanned using a flatbed scanner. Roots were scanned at a resolution of 300dpi. Scanned images were processed using WinRhizo root image processing software. Estimates were obtained from total root length, root surface area, average root diameter, and root length density. Scanned roots were spread for drying to estimate root mass in each sample.

Plant assessment data was analyzed using SAS statistical analysis software. Treatment means and standard errors were estimated for each parameter. Analysis of variance for a randomized complete block design was used to determine if there were significant differences among treatments for each plant assessment parameter. Corn plots were analyzed several ways. The two corn plants were first compared with each other using analysis of variance with time or planting as the treatment. The three vegetation treatments were compared with each other in the second analysis using only the Time 2 for corn growth, as well as, the Time 2 data for the natural revegetation and willow treatments. In the third analysis, the total root production and biomass from the two plantings of corn were compared with natural revegetation and willow sampled at Time 2. Presumably the benefit of growing successive corn crops would increase potential phytoremediation activity. Correlation coefficients were calculated within each treatment to examine the relationships between different plant assessment parameters.

Results

Digital photographs of each plot at the two sampling times are shown in Figure 1 and Figure 2. Both sets of photographs show good canopy development in corn and natural vegetation plots. The willow plots show good plant survival but rather limited growth of trees during this second growing season. Figure 1 illustrates the challenge of controlling vegetation in the plant suppression plots and as volunteer growth in the willow treatments. Significant efforts were made to control volunteer vegetation; however, the cycles of weed growth followed by control measures may affect treatment comparisons. This observation is common in many phytoremediation trials. Volunteer vegetation in the plant suppression plots and in the willow plots was well controlled at the time of the second plant assessment event.

Figure 1 and Figure 2 show the corn treatments were beginning to tassel at the time of the plant assessments. This suggests corn biomass production probably reached close to its maximum potential for each of the corn crops. The stature of the corn plants was quite short indicating that corn growth may have been much less than is usually observed in optimal corn growing conditions. The limited corn growth may be either due to the varieties of corn that were used or due to growth limiting conditions at the site. One important growth limiting condition was the shallow soil depth (about 15 cm) of the treated soil.

Table 1 summarizes corn growth at Time 1 and Time 2. Percentage cover was almost 100% in the corn plots for each crop. Plant height was similar for both crops at 74 cm. Aboveground biomass was similar for both plantings. However root mass was significantly greater in the first planting compared to the second planting. Since the plant rooting depth was limited by the depth of the treated soil, the root mass estimate for the corn plots may be a good estimate of total corn root mass. The ratio of root mass to aboveground biomass is only about 10% for the corn plots. A higher ratio of root mass to aboveground biomass would usually be expected. This further indicates that limited soil volume may have limited corn growth potential.

Table 2 shows the treatment means for each vegetation treatment at the second sampling event. Both the corn and natural revegetation treatments showed nearly 100% vegetation cover while the willow plots has less than 10% vegetation cover. This is a clear indication that the willow plantings have not fully developed by the end of the second growing season. Root growth in the willow plots was also limited compared to the other treatments. This should be taken into consideration in interpreting the results of this trial. The similarity of average root diameter in the willow plots compared to the other treatments also indicates that a limited number of tree roots were recovered in the sampled soil cores. Willow roots would usually be expected to have higher root diameter then the other herbaceous species especially grasses found in this study. The natural revegetation treatment had significantly higher root production than either the corn or willow treatments. These results indicate that natural recovery of vegetation produced good root growth under a low management treatment scheme.

Table 3 compares the total of two corn crops with the other treatments. In this comparison, the corn plots produced higher aboveground biomass than the natural revegetation plots. Although root parameters for the total corn data were higher than for the natural revegetation treatment, most of these differences were not statistically significant. These results show, however, that an intensively managed cropping system such as several corn plantings combined with clover could produce greater root growth than a less intensively managed system. System performance, management considerations, and economics would determine if an intensively managed plant system is warranted compared to a minimally managed plant system. During the limited term of this trial, the corn and natural revegetation treatments clearly produced greater root growth than the willow treatment. A longer term treatment system would be needed for effective assessment of the willow treatment.

Correlation coefficients between each pair of plant assessment parameter were calculated within each of the vegetation treatments (Table 4). Aboveground plant growth, either measured as plant height or as aboveground biomass production was not correlated with root growth parameters. This suggests that under the conditions of this trial, it was necessary to evaluate plant root growth separately from aboveground growth to understand the extent of plant root development. Root mass, root length, root surface area, and root length density were all highly correlated. This observation held for each treatment. The association of root parameter estimates suggests that an assessment of root mass may provide as a reasonable estimate of plant density. Root mass is easier to measure than root length and density. This observation may be helpful in planning future trials.

Assessment of the vegetation composition of the natural revegetation treatment was important for determining which plant species occupied the site. The plant community at Jones Island CDF represents an early stage of ecological succession. Composition of the plant community would be expected to change with the length of time the plots are allowed to grow. Table 5 summarizes plant species composition and percent coverage in the natural revegetation plots at the end of the growing season. Twenty-four total plant species from 12 plant families were identified in the natural revegetation plots. Nine of the species were members of the Asteraceae or sunflower family. The dominant species in all plots was *Phalaris arundinacea* L. or reed canarygrass. In plots 1 and 2 reed canarygrass represented about 90% of the vegetation coverage. Plots 3 and 4 had greater diversity than plots 1 and 2. Reed canarygrass represented about 50 to 60% of the species coverage in these plots. The proportion of bare ground in the plots was limited to an overall average of 5%. Only plant species present within the sample quadrats at the time of the assessment in late September were recorded in this survey. Additional species were present in other part of the plots and at other times during the growing season. These results show the treated soil can support diverse plant communities from seeds naturally present at the confined disposal facility.

Conclusions

Plant growth was assessed two times during the 2002 growing season at the Dredged Material Reclamation Demonstration. The assessments showed that vegetation treatments were successfully established at the site. The corn and natural revegetation treatments had good coverage of the plots. The natural revegetation treatment showed rapid colonization of the plots with a diverse plant community dominated by *Phalaris arundinacea* (reed canarygrass). Aboveground biomass production and root growth in the natural revegetation plots was superior to a single planting of corn. Two crops of corn, however, produced growth that equaled the natural revegetation plots indicating that an intensively managed plant system may be able to produce high plant biomass. The sandbar willow trees survived well although they had not grown sufficiently by the end of the second growing season to demonstrate their full potential impact on the treated soil.

Overall, the shallow depth of the soil in the treatment system probably limited plant growth and root development. Both corn plantings reached a mean plant height of 74 cm. The soil depth in most of the trial was 15 cm (6 inches). The soil depth likely limited plant nutrient availability and may have increased irrigation needs than would probably be expected in a system with a deeper soil profile.

Correlations among plant assessment parameters showed that aboveground biomass production was not correlated with root growth. Therefore, it is necessary to sample roots to determine the extent of plant root development. In this trial, root mass was highly correlated with root length, root surface area, and root length density indicating that estimation of root mass may be a useful indicator of plant root development in vegetative remediation trials similar to this one.

Table 1. Corn treatment means and standard errors for the plant assessment parameters sampled at the end of two cropping cycles. Sample size is 12 for each parameter.

Variable		Time1 -- Corn *mean*	±	*se*	Time2 -- Corn *mean*	±	*se*
Vegetation cover	%	97.3	±	1.3	97.3	±	1.7
Plant height	cm	73.9	±	4.9	73.7	±	5.2
Aboveground biomass	g/m^2	524.7	±	56.7	505.3	±	43.3
Root mass*	g/m^2	61.4	±	6.1	34.2	±	5.3
Root length*	cm	2347.9	±	299.2	1527.1	±	326.5
Root surface area*	cm^2	384.7	±	53.3	234.3	±	44.5
Average root diameter	mm	0.51	±	0.01	0.52	±	0.02
Root length density	cm/cm^3	3.0	±	0.4	2.1	±	0.4

* Means for Time 1 and Time 2 are different by a paired t-test with $p \leq 0.05$.

Table 2. Vegetation treatment means and standard errors for the plant assessment parameters sampled on 9/23/02. Sample size is 12 for each parameter. Means followed by the same letter within a row are not significantly different by a paired t-test with $p \leq 0.05$.

Variable	Units	Time2 -- Corn				Time2 -- Natural Reveg.				Time2 -- Willow			
		mean	±	*se*		*mean*	±	*se*		*mean*	±	*se*	
Vegetation cover	%	97.3	±	1.7	a	94.6	±	2.5	a	8.8	±	1.3	b
Plant height	cm	73.7	±	5.2		94.9	±	6.5		71.3	±	5.6	
Aboveground biomass	g/m^2	505.3	±	43.3		540.3	±	65.3					
Root mass	g/m^2	34.2	±	5.3	b	116.1	±	29.2	a	24.9	±	5.9	b
Root length	cm	1527.1	±	326.5	b	3096.7	±	468.2	a	718.7	±	238.1	b
Root surface area	cm^2	234.3	±	44.5	b	455.8	±	85.9	a	117.4	±	39.8	b
Average root diameter	mm	0.52	±	0.02		0.45	±	0.02		0.52	±	0.02	
Root length density	cm/cm^3	2.1	±	0.4	b	4.4	±	0.6	a	1.0	±	0.33	b

Table 3. Vegetation treatment means and standard errors for the plant assessment parameters using the total of two corn crops sampled on 7/29/02 and 9/23/02 and natural revegetation and willow treatment sampled on 9/23/02. Sample size is 12 for each parameter. Means followed by the same letter within a row are not significantly different by a paired t-test with $p \leq 0.05$.

Variable		Corn -- Total				Time2 -- Natural Reveg.				Time2 -- Willow			
		mean	±	*se*		*mean*	±	*se*		*mean*	±	*se*	
Vegetation cover	%	97.3	±	1.4	a	94.6	±	2.5	a	8.8	±	1.3	b
Plant height	cm	73.8	±	2.9	b	94.9	±	6.5	a	71.3	±	5.6	b
Aboveground biomass	g/m^2	1030.0	±	47.7	a	540.3	±	65.3	b				
Root mass	g/m^2	95.6	±	5.3	a	116.1	±	29.2	a	24.9	±	5.9	b
Root length	cm	3875.0	±	281.7	a	3096.7	±	468.2	a	718.7	±	238.1	b
Root surface area	cm^2	619.0	±	48.1	a	455.8	±	85.9	b	117.4	±	39.8	c
Average root diameter	mm	0.52	±	0.01	a	0.45	±	0.02	b	0.52	±	0.02	a
Root length density	cm/cm^3	5.1	±	0.4	a	4.4	±	0.6	a	1.0	±	0.3	b

Table 4. Pearson correlation coefficients of plant assessment parameters for two corn plantings. Sample size is 12. The upper value is the correlation coefficient. The lower value is the probability value the correlation is not greater than zero.

Time 1 -- Corn	Plant Height	Aboveground Biomass	Root Mass	Root Length	Root Surface Area	Average Root Diameter	Root Length Density
Percentage cover	0.59	0.73	0.44	0.41	0.44	0.45	0.32
Plant height		0.81	0.31	0.34	0.38	0.30	0.19
Aboveground biomass			0.58	0.40	0.39	0.29	0.28
Root mass				0.90	0.85	0.25	0.88
Root length					0.98	0.35	0.97
Root surface area						0.49	0.95
Avg. root diameter							0.38

Time 2 -- Corn	Plant Height	Aboveground Biomass	Root Mass	Root Length	Root Surface Area	Average Root Diameter	Root Length Density
Percentage cover	-0.56	-0.58	-0.43	-0.61	-0.51	0.62	-0.61
Plant height		0.77	0.04	0.19	0.09	-0.50	0.19
Aboveground biomass			0.32	0.42	0.36	-0.62	0.42
Root mass				0.95	0.98	-0.52	0.95
Root length					0.99	-0.72	0.99
Root surface area						-0.64	0.99
Avg. root diameter							-0.72

Table 4 (continued). Pearson correlation coefficients of plant assessment parameters for natural revegetation and willow treatments. Sample size is 12. The upper value is the correlation coefficient. The lower value is the probability value the correlation is not greater than zero.

Time 2 -- Natural reveg.	Plant Height	Aboveground Biomass	Root Mass	Root Length	Root Surface Area	Average Root Diameter	Root Length Density
Percentage cover	0.50	0.58	-0.01	-0.34	-0.22	0.14	-0.33
Plant height		0.43	0.11	-0.06	0.04	0.15	-0.07
Aboveground biomass			0.49	-0.02	0.23	0.72	0.03
Root mass				0.69	0.89	0.89	0.70
Root length					0.94	0.37	0.99
Root surface area						0.65	0.94
Avg. root diameter							0.41

Time 2 -- Willow	Plant Height	Root Mass	Root Length	Root Surface Area	Average Root Diameter	Root Length Density
Percentage cover	-0.09	-0.13	0.07	0.10	0.38	0.07
Plant height		0.21	0.12	0.11	-0.25	0.11
Root mass			0.81	0.82	0.23	0.81
Root length				0.99	0.05	0.99
Root surface area					0.12	0.99
Avg. root diameter						0.05

Table 5. Mean percentage vegetation cover in four natural revegetation treatment plots assessed on September 23, 2002. Each mean is based three quadrats sampled per plot. The percentage of bare ground is listed first followed by plant species in descending order of overall dominance.

Family	Species	Common name	Plot 1 (mean)	Plot 2 (mean)	Plot 3 (mean)	Plot 4 (mean)	Total
Bare ground			0.0	0.0	13.3	8.3	5.4
Poaceae	*Phalaris arundinacea* L.	reed canarygrass	89.7	90.3	47.0	62.7	72.4
Apiaceae	*Daucus carota* L.	Queen Anne's Lace	1.0	1.3	5.0	2.0	2.3
Asteraceae		thistle (sp. not identified)	1.7	0.0	1.7	5.3	2.2
Chenopodiaceae	*Atriplex* sp.	atriplex (not identified)	0.7	1.0	5.3	1.0	2.0
Asteraceae	*Symphyotrichum* sp.	aster1 (sp. not identified)	0.0	5.1	0.0	3.0	2.0
Asteraceae	*Ambrosia* sp.	ragweed (sp. not identified)	0.4	0.7	0.0	6.7	1.9
Asteraceae	*Helianthus annuus* L.	common sunflower	0.0	0.7	7.0	0.0	1.9
Asteraceae	*Conyza canadensis* (L.) Conq.	Canadian horseweed	0.0	0.7	2.0	5.0	1.9
Asteraceae	*Arctium minus* Bernh.	lessor burdock	5.0	0.0	1.7	0.0	1.7
Asteraceae	*Symphyotrichum* sp.	aster2 (sp. not identified)	0.0	0.0	6.3	0.0	1.6
Asteraceae	*Ambrosia artemisiifolia* L.	ragweed	0.4	0.7	1.7	2.3	1.3
Polygonaceae	*Polygonum lapathifolium* L.	curlytop knotweed	0.0	1.0	2.3	0.7	1.0
Fabaceae	*Melilotus officinalis* (L.) Lam.	yellow sweetclover	0.0	0.0	3.0	0.7	0.9
Plantaginaceae	*Plantago major* L.	common plantain	0.0	0.0	2.0	0.0	0.5
Asteraceae	*Sonchus oleraceus* L	common sowthistle	0.0	0.0	0.7	1.0	0.4
Lamiaceae	*Nepeta cataria* L	catnip	0.7	0.0	0.0	0.7	0.3
Brassicaceae	*Sisymbrium officinale* (L.) Scop.	mustard	0.0	0.0	0.3	0.7	0.3
Apocynaceae	*Apocynum* sp.	hemp dogbane	0.3	0.3	0.0	0.0	0.2
Poaceae	*Echinochloa crus-galli* (L.) Beauv.	barnyardgrass	0.0	0.0	0.4	0.0	0.1
Poaceae	*Hordeum jubatum* L.	foxtail barley	0.0	0.0	0.3	0.0	0.1
Polygonaceae*	*Rumex salicifolius* Weinm.	willow dock	0.0	0.0	0.0	0.0	0.0
Rosaceae*	*Potentilla norvegica* L.	Norwegian cinquefoil	0.0	0.0	0.0	0.0	0.0
Poaceae*	*Agrostis stolonifera* L.	creeping bentgrass	0.0	0.0	0.0	0.0	0.0
Onagraceae*	*Oenothera biennis* L.	common evening-primrose	0.0	0.0	0.0	0.0	0.0

* Species observed in one quadrat only in low proportion.

Figure 1. Phytoremediation trial individual plot photographs were taken on July 29, 2002. Images were taken from the top of the berm on the east side of each plot looking westward. Cell 1 is on the southern side of the trial.

Cell 1

Plant Suppression | Natural Revegetation | Sandbar Willow | Corn

Cell 2

Corn | Plant Suppression | Natural Revegetation | Willow

Figure 1 (continued).

Cell 3

Corn Natural Revegetation Sandbar Willow Plant Suppression

Cell 4

Natural Revegetation Plant Suppression Sandbar Willow Corn

Figure 2. Phytoremediation trial individual plot photographs were taken on September 23, 2002. Images were taken from the top of the berm on the east side of each plot looking westward. Cell 1 is on the southern side of the trial.
September 23, 2002

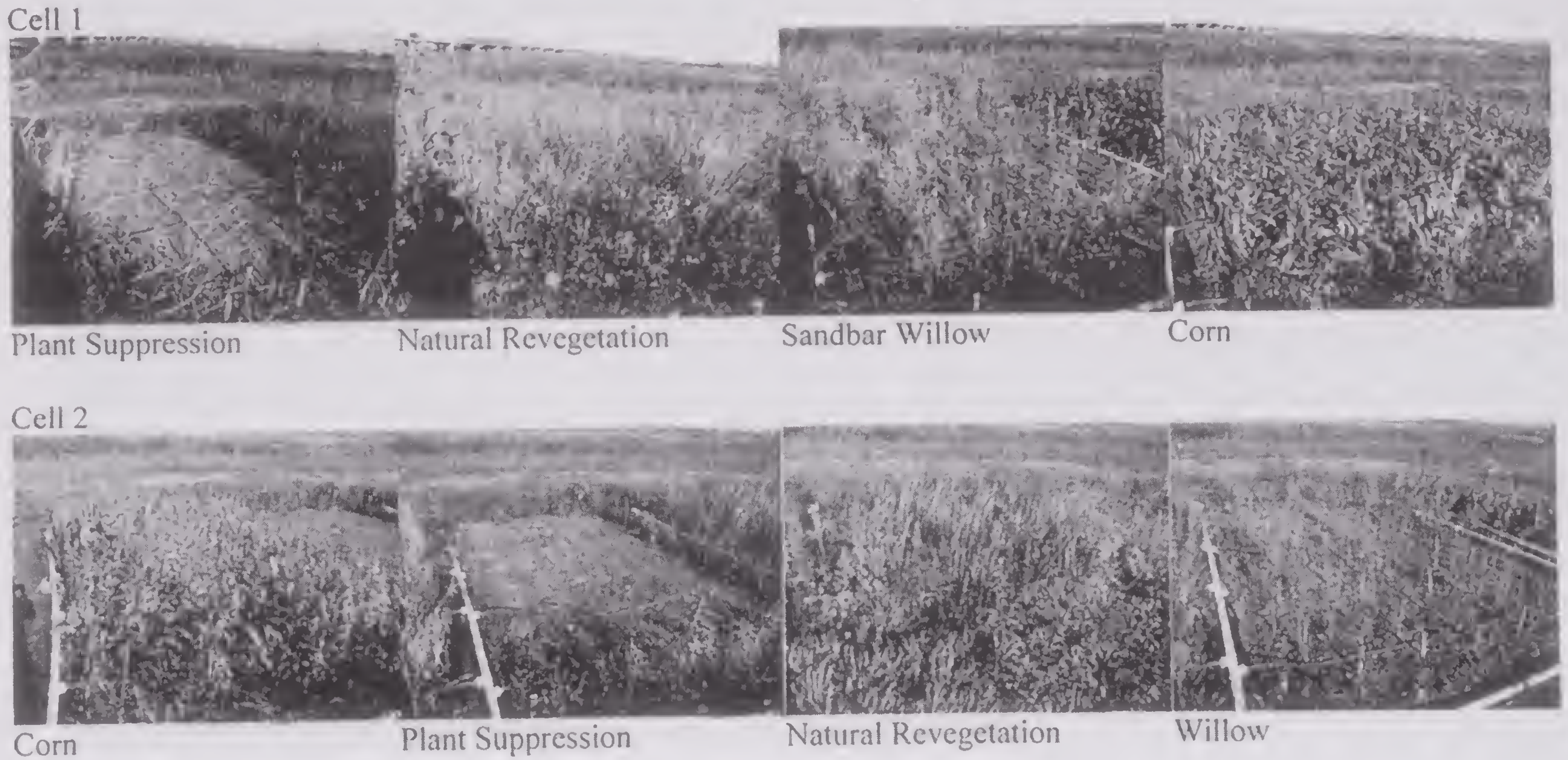

Figure 2 (continued).

Cell 3

Corn | Natural Revegetation | Sandbar Willow | Plant Suppression

Cell 4

Natural Revegetation | Plant Suppression | Sandbar Willow | Corn

APPENDIX 1

SCOPE OF WORK
EPA Contract Number: 68-C-00-179, T.O. # 7
SAIC Project Number: 01-0835-08-2178

May 9, 2002

Title: Dredged Material Reclamation Demonstration at the Jones Island CDF, Milwaukee, Wisconsin.

Estimated Period of Performance: June 2002 to February 2003

SAIC Task Order Manager:
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Background Information. The Jones Island confined disposal facility (CDF), located just south of Milwaukee, Wisconsin, is one of 26 federally funded CDFs built in the Great Lakes as a once cost-effective means to manage materials dredged during navigation maintenance projects. However, many Great Lakes CDFs are now nearing or exceeding design capacity and the cost of creating new facilities is prohibitive. The U.S. Army Corps of Engineers (USACE) is actively seeking alternatives for the CDFs and for current and future inventories of dredged materials.

In 1997, the USACE began a series of experiments at the Jones Island CDF (Milwaukee, WI) using biopiles to reduce the concentration of polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs) in dredged material scraped from a borrow area within the CDF. The experiments demonstrated some success, and now the USACE has partnered with the U.S. Environmental Protection Agency's (USEPA) Superfund Innovative Technology Evaluation (SITE) program to expand the test program to explore phytoremediation as a potential reclamation process.

Project Description. This project is part of the USACE strategy to develop beneficial uses for dredged material by creating a system to "manufacture" marketable topsoil that will meet the requirements of a variety of potential end users. Four (4) treatments are being tested currently at the Jones Island CDF to determine the ability of each to remove PCBs, PAHs, and gross organics from dredged materials.

The first treatment involves corn. A fast-maturing corn hybrid is used to begin the treatment cycle in mid-June. After 45 days, the first crop is tilled in and a second corn planting occurs.

Again, after 45 days, the second corn is tilled in and a winter cover of clover (optional) may be planted.
The second treatment involves planting 24-inch Sandbar willow cuttings; a third treatment consists of allowing natural vegetation present as seeds in the borrow area soil to take root and grow; and the fourth treatment consists of allowing natural microbial activity to act on the test soil mass while actively suppressing plant growth with a post-emergent herbicide.

The four treatments are being evaluated in four (4) replicate test plots, nominally 60 ft x 20 ft in size. Each test plot consists of four (4) treatment cells (nominally 12 ft x 20 ft) to which the four treatments have been assigned in a random fashion. The schematic below is an example test plot.

Test Plot 1

	Natural Veg.		**Sandbar Willow**		**Corn/ Clover**		**Plant Supprsn**	

Dredged material selected from a 0-ft to 1-ft area within the CDF was excavated, screened, mixed, and placed into each cell to create a soil bed with a depth of about 1 ft. The test plots are being maintained for two full growing seasons (June 2001 through September 2002) according to the following schedule:

- **T=0**, apply fertilizers (P and K) plant 1^{st} corn, June 15, 2001
- Plant Sandbar willow, June22, 2001
- Incorporate corn, add additional N, P, K, plant 2^{nd} corn, August 1-15
- **T=1**, incorporate corn and add additional P and K, May 20-25, 2002
- Plant 3^{rd} corn, June 15-30, 2002
- Incorporate corn, add additional N, P, K, plant 4^{th} corn, August 1-15, 2002
- **T=2**, incorporate corn, September 15-30, 2002

Subcontractor Services. SAIC requires subcontractor support to perform plant assessments at predetermined intervals throughout both growing seasons. The plant assessments are those recommended in the Phytoremediation Action Team Field Study Protocol issued by the Remediation Technologies Demonstration Forum (RTDF) in July 1999 (http://www.rtdf.org/public/phyto/phytodoc.htm). The plant assessments are described below in Tasks 1 through 3 of this Statement of Work (SOW).
The subcontractor will provide pricing information (labor, materials, travel, and other direct costs) for all four tasks. On-site labor for plant and root sampling will be provided by SAIC. No plant assessments were performed during the 2001 growing season.

Task 1: Percent Cover

Description. A 0.5-m square frame (quadrat) will be placed randomly at two spots on each planted cell. A rating scale of 0%-100% will be used to assess the amount of bare ground and plant cover. Example: 20% of total plot area is bare ground, 80% of total plot area is covered with plants. Total should add up to 100 (e.g. 20% + 80% = 100%).

Frequency. For corn cells, a percent cover will be performed during the week prior to planting a new corn rotation, just before the current crop is incorporated. For example, the first percent

cover will be performed on the corn cells in late July or early August 2002, approximately 45 days after planting.

For the natural vegetation cells, a percent cover will be performed at the end of the second growing season (T=2). Additionally, a vegetative survey will be performed to identify species in the natural vegetation plots.

For the Sandbar willow cells, a percent cover will be performed at the end of the second growing season (T=2).

Task 2: Shoot Biomass

Description. Shoot biomass is the amount of dry plant material produced in grams per square meter. Vegetation within the area covered by the sample frame will be clipped down to the ground surface, placed into paper bags, shipped to a central processing location, dried in an oven, and weighed. Vegetation leaning outside the frame will not be included. Tree biomass in the Sandbar willow plots and natural vegetation plots will be assessed by measuring stem diameter and plant height for all trees growing inside a two-foot border in each plot.

Frequency. A shoot biomass assessment will be performed on each quadrat in conjunction with percent cover assessments.

Task 3: Root Parameters

Description. Root parameters include biomass, length, density, surface area, and diameter. Within each quadrat, one (1) full profile core samples (0 in - 12 in) will be collected for evaluation using a 3 ¼ -in diameter coring device. Root parameters will be reported in two depth intervals of 0 – 6 and 6 – 12 inches. Evaluation to be performed per RTDF Phytoremediation Field Study Protocol.

Frequency. To be performed in parallel with percent cover and shoot biomass using same quadrats.

Task 4: Data Reporting

The subcontractor will state routine turn-around time for data reporting. Final report package must include a narrative detailing any problem with the assessments as well as tabulated and cross-referenced sample results. The final report for each growing season will be submitted four months after the last field sampling.

In addition, preliminary results may be requested as draft data to be transmitted via fax to the attention of the SAIC TOM as data become available after sample analysis but before formal data reporting.

Table 1. Plant Assessment Frequency

Time	Description	Assessment	Total Quadrats	Total Soil Cores
T=0-2	Corn - collected at end of each corn cycle from four clover/corn treatment cells, estimated to be in late July and mid-Sept.	Percent Cover, Shoot Biomass	16	--
		Root Parameters	--	16
T=1,2	Natural Vegetation - collected at end of each growing season from four natural vegetation treatment cells, est. mid-Sept.	Percent Cover, Shoot Biomass, Vegetation Survey	8	--
		Root Parameters	--	8
T=1,2	Willows - collected at the end of each growing season from four willow treatment cells, est. mid-Sept.	Percent Cover, Tree height and diameter	whole plot	--
		Root Parameters	--	8

3.9 Additional Requirements

- **The vendor should immediately report any technical problems to the SAIC QC Coordinator or TOM so that appropriate corrective actions can be determined.**

- SAIC will supply in-field labor assistance.

- The vendor will need to inform SAIC how samples will be disposed of and whether the laboratory requires that samples be returned to SAIC after analysis.

5.0 Points of Contacts

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APPENDIX 2

Appendix 2. Original data from plant assessments Time 1 and Time 2.

Plot	Treat	Time	Quad	Depth cm	Perc. Cover	Plant Height (cm)	Aboveground Biomass (g/m^{2})	Root Mass (g/m^{2})	Root Length (cm)	Root Surface Area (cm^{2})	Average Root Diameter (mm)	Root Length Density (cm/cm^{3})
1	c	1	1	15.2	100	92	800	74.3	2593	380.3	0.47	2.9
1	c	1	2	16.5	100	90	616	61.7	2618	471.7	0.57	3.6
1	c	1	3	17.8	100	94	768	81.2	2991	477.3	0.51	3.5
2	c	1	1	15.2	99	86	772	73.7	2177	371.0	0.54	2.6
2	c	1	2	14.0	100	90	552	82.9	4353	790.5	0.58	5.0
2	c	1	3	14.6	100	80	536	31.8	1052	170.3	0.52	1.5
3	c	1	1	17.8	98	46	304	66.6	2345	366.8	0.5	3.2
3	c	1	2	18.4	90	53	332	35.0	838	137.8	0.52	1.3
3	c	1	3	15.2	90	58	364	79.1	3224	503.2	0.5	4.6
4	c	1	1	19.1	100	69	476	50.0	2062	372.0	0.57	2.8
4	c	1	2	15.2	100	62	572	77.6	2990	452.9	0.48	3.8
4	c	1	3	17.8	90	67	204	22.8	932	123.3	0.42	1.1
1	c	2	1	15.24	100	97	656	38.1	1787	270.8	0.48	2.5
1	c	2	2	15.24	100	96	576	14.0	473	78.0	0.52	0.7
1	c	2	3	15.24	80	112	828	50.0	2902	376.7	0.41	4.0
1	n	2	1	13.97	100	85	672	43.7	2147	276.1	0.41	3.2
1	n	2	2	12.7	100	95	980	138.3	2314	398.0	0.55	3.8
1	n	2	3	15.24	100	87	584	168.5	2196	355.9	0.52	3.0
1	w	2	1	15.24	10	62		49.8	1154	188.3	0.52	1.6
1	w	2	2	15.24	5	48		32.2	639	103.8	0.52	0.9
1	w	2	3	15.24	20	48		10.9	328	70.4	0.68	0.5
2	c	2	1	15.24	100	70	420	20.5	544	104.9	0.61	0.8
2	c	2	2	15.24	92	70	444	60.5	3648	493.2	0.43	5.0
2	c	2	3	15.24	100	55	460	68.4	2845	460.7	0.52	3.9
2	n	2	1	15.24	100	125	528	61.7	3204	392.9	0.39	4.4
2	n	2	2	13.97	100	105	520	63.2	1269	186.6	0.47	1.9
2	n	2	3	15.24	100	130	940	385.1	5700	1149.0	0.64	7.8
2	w	2	1	15.24	10	80		68.9	3222	535.7	0.53	4.4
2	w	2	2	15.24	10	98		22.0	567	100.6	0.56	0.8
2	w	2	3	12.7	10	68		10.5	305	47.4	0.5	0.4
3	c	2	1	15.24	100	60	356	21.6	453	86.9	0.61	0.6
3	c	2	2	15.24	100	64	468	13.2	642	91.3	0.45	0.9
3	c	2	3	15.24	100	70	668	45.2	1977	320.2	0.52	2.7
3	n	2	1	15.24	85	52	308	191.7	5484	821.2	0.48	7.5
3	n	2	2	15.24	75	73	304	148.6	5076	716.1	0.45	7.0
3	n	2	3	15.24	100	75	424	55.9	1780	212.6	0.38	2.4
3	w	2	1	15.24	5	103		49.6	521	93.0	0.57	0.7
3	w	2	2	13.97	5	57		13.0	270	43.3	0.51	0.4
3	w	2	3	15.24	5	53		13.8	517	75.1	0.46	0.7
4	c	2	1	15.24	100	70	292	25.5	839	151.0	0.57	1.2
4	c	2	2	15.24	95	60	464	34.7	1755	287.9	0.52	2.4
4	c	2	3	15.24	100	60	432	18.2	460	90.0	0.62	0.6
4	n	2	1	15.24	100	115	364	50.0	4104	464.6	0.36	5.6
4	n	2	2	15.24	90	92	504	54.0	2794	361.0	0.41	3.8
4	n	2	3	13.97	85	105	356	32.0	1093	135.8	0.4	1.6
4	w	2	1	15.24	10	77		7.5	481	62.7	0.42	0.7
4	w	2	2	15.24	5	68		12.6	286	50.4	0.56	0.4
4	w	2	3	15.24	10	97		8.0	333	37.8	0.36	0.5

APPENDIX 3

Appendix 3. Original data for percentage vegetation cover in four natural revegetion treatment plots assessed on September 23, 2002. Three quadrats were sampled per plot. The percentatge of bare ground is listed first followed by plant species in descending order of overall dominance.

Family	Species	Common name	Plot 1 Quadrat			Plot 2 Quadrat			Plot 3 Quadrat			Plot 4 Quadrat		
			1	2	3	1	2	3	1	2	3	1	2	3
Bareground			0	0	0	0	0	0	15	25	0	0	10	15
Poaceae	*Phalaris arundinacea* L.	reed canarygrass	93	98	78	81	90	100	66	20	55	65	64	59
Apiaceae	*Daucus carota* L.	Queen Anne's Lace	0.1	1	2	2	2	0	3	10	2	5	1	0
Asteraceae		thistle (sp. not identified)	5	0	0	0	0	0	2	1	2	3	3	10
Chenopodiaceae	*Atriplex* sp.	atriplex (not identified)	2	0	0.1	1	2	0.1	2	10	4	0	1	2
Asteraceae	*Symphyotrichum* sp.	aster1 (sp. not identified)	0	0	0	10		0.1	0	0	0	0	5	4
Asteraceae	*Ambrosia* sp.	ragweed (sp. not identified)	0.1	0	1	1	1	0	0	0	0	20	0	0.1
Asteraceae	*Helianthus annuus* L.	common sunflower	0	0.1	0	1	1	0	0	1	20	0	0	0
Asteraceae	*Conyza canadensis* (L.) Conq.	Canadian horseweed	0	0	0	0	2	0	0	4	2	3	10	2
Asteraceae	*Arctium minus* Bernh.	lessor burdock	0	0	15	0	0	0	0	0	5	0	0	0
Asteraceae	*Symphyotrichum* sp.	aster2 (sp. not identified)	0	0	0	0	0	0	4	10	5	0	0	0
Asteraceae	*Ambrosia artemisiifolia* L.	ragweed	0	0.1	1	2	0	0	0	5	0	0	4	3
Polygonaceae	*Polygonum lapathifolium* L.	curlytop knotweed	0	0	0	1	2	0	0	5	2	0	0	2
Fabaceae	*Melilotus officinalis* (L.) Lam.	yellow sweetclover	0	0	0	0	0	0	2	7	0	0	2	0
Plantaginaceae	*Plantago major* L.	common plantain	0	0	0	0	0	0	4	0	2	0	0	0
Asteraceae	*Sonchus oleraceus* L	common sowthistle	0.1	0	0	0	0	0	0	2	0	0	0	3
Lamiaceae	*Nepeta cataria* L	catnip	0	0	2	0	0	0	0	0	0	2	0	0
Brassicaceae	*Sisymbrium officinale* (L.) Scop.	mustard	0	0	0	0.1	0	0	0	0	1	2	0	0
Apocynaceae	*Apocynum* sp.	hemp dogbane	0	0	1	1	0	0	0	0	0	0	0	0
Poaceae	*Echinochloa crus-galli* (L.) Beauv.	barnyardgrass	0	0	0	0	0	0	1	0.1	0	0	0	0
Poaceae	*Hordeum jubatum* L.	foxtail barley	0	0	0	0	0	0	1	0	0	0	0	0
Polygonaceae*	*Rumex salicifolius* Weinm.	willow dock	0	0.1	0	0	0	0	0	0	0	0	0	0
Rosaceae*	*Potentilla norvegica* L.	Norwegian cinquefoil	0	0	0.1	0	0	0	0	0	0	0	0	0
Poaceae*	*Agrostis stolonifera* L.	creeping bentgrass	0	0	0	0	0	0	0	0	0	0	0	0
Onagraceae*	*Oenothera biennis* L.	common evening-primrose	0	0	0	0	0	0	0	0	0	0	0	0

* Species observed in one quadrat in low proportion.

APPENDIX 4

Appendix 4. Mean plant height and stem diameter of willow trees measured within quadrats sampled on September 23, 2002.

Plot	Quadrat	N	Mean plant height	Plot mean	Mean stalk diameter	Plot mean	Mean branch diameter	Plot mean
1	1	3	61.7		9.7		4.0	
1	2	2	47.5		10.0		2.0	
1	3	3	48.3	59.4	10.7	10.3	3.3	3.2
2	1	2	80.0		10.7		3.3	
2	2	2	97.5		10.3		4.3	
2	3	3	68.3	87.1	13.3	12.0	3.7	3.5
3	1	2	102.5		13.7		2.7	
3	2	3	56.7		11.3		3.7	
3	3	2	52.5	72.1	8.3	13.9	1.3	3.3
4	1	3	76.7		22.3		5.7	
4	2	2	67.5		9.3		2.3	
4	3	3	96.7	80.3	17.3	16.3	6.0	4.7

APPENDIX 5

Analysis of Variance for Plant Assessment Parameters
Tests of Treatment Differences Time 2 Sampling on 9/23/02

Dependent Variable: Percentage Cover

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	50	17	0.8	0.548
Treatment	2	20276	10138	473.8	<.0001
Error	6	128	21		
Total	11	20454			

R-Square	CV	Root MSE	Percentage Cover Mean
0.99	6.92	4.63	66.86

Dependent Variable: Plant height

Source	DF	Sum of Squares	Mean Square	FValue	Pr > F
Plot	3	749	250	0.6	0.624
Treatment	2	1352	676	1.7	0.261
Error	6	2391	398		
Total	11	4491			

R-Square	CV	Root MSE	Plant height Mean
0.47	24.96	19.96	79.97 cm

Dependent Variable: Aboveground biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	126134	42045	3.6	0.162
Treatment	1	2450	2450	0.2	0.680
Error	3	35389	11796		
Total	7	163973			

R-Square	CV	Root MSE	Aboveground biomass Mean
0.78	20.77	108.61	522.83 gm

Dependent Variable: Root Mass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	5057	1686	2.6	0.144
Treatment	2	20144	10072	15.8	0.004
Error	6	3834	639		
Total	11	29036			

R-Square	CV	Root MSE	Root Mass Mean
0.87	43.30	25.28	58.38 g/m^2

Dependent Variable: Root Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	1768928	589643	1.6	0.276
Treatment	2	11696417	5848209	16.3	0.004
Error	6	2151138	358523		
Total	11	15616483			

R-Square	CV	Root MSE	Root Length Mean
0.86	33.62	598.77	1780.83 cm

Dependent Variable: Root Surface Area

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	66796	22265	3.7	0.080
Treatment	2	236364	118182	19.7	0.002
Error	6	35964	5994		
Total	11	339123			

R-Square	CV	Root MSE	Root Surface Area Mean
0.89	28.76	77.42	269.16 cm^2

Dependent Variable: Average Root Diameter

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	0.004	0.001	0.50	0.698
Treatment	2	0.012	0.006	2.02	0.213
Error	6	0.017	0.003		
Total	11	0.033			

R-Square	CV	Root MSE	Average Root Diameter Mean
0.48	10.74	0.05	0.50 mm

Dependent Variable: Root Length Density

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	3.2	1.1	1.8	0.244
Treatment	2	23.5	11.7	20.1	0.002
Error	6	3.5	0.6		
Total	11	30.2			

R-Square	CV	Root MSE	Root Length Density Mean
0.88	30.85	0.77	2.48 cm/cm^3

Comparisons of Least Squares Treatment Means from Time 2
Means followed by the same letter are not different by paired t-test.

Treatment	Percentage cover lsmeans	Standard Error	
Corn	97.3	2.3	a
Natural reveg.	94.6	2.3	a
Willow	8.8	2.3	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.446	<.0001
Natural reveg.		<.0001

Treatment	Plant height lsmeans	Standard Error	
Corn	73.7	10.0	a
Natural reveg.	94.9	10.0	a
Willow	71.3	10.0	a

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.183	0.873
Natural reveg.		0.146

Treatment	Aboveground biomass lsmeans	Standard Error	H0:LSMean1= LSMean2 Pr > |t|
Corn	505.3	54.3	0.680
Natural reveg.	540.3	54.3	

P values for paired t-tests:

Treatment	Root mass lsmeans	Standard Error	
Corn	34.2	12.6	a
Natural reveg.	116.1	12.6	b
Willow	24.9	12.6	a

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.004	0.622
Natural reveg.		0.002

Treatment	Root length lsmeans	Standard Error	
Corn	1527	299	b
Natural reveg.	3097	299	a
Willow	719	299	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.010	0.105
Natural reveg.		0.001

Treatment	Root surface area lmeans	Standard Error	
Corn	234	39	b
Natural reveg.	456	39	a
Willow	117	39	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.007	0.077
Natural reveg.		0.001

Treatment	Root diameter lsmeans	Standard Error	
Corn	0.52	0.03	a
Natural reveg.	0.45	0.03	a
Willow	0.52	0.03	a

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.117	0.852
Natural reveg.		0.153

Treatment	Root length density lsmeans	Standard Error	
Corn	2.1	0.4	b
Natural reveg.	4.4	0.4	a
Willow	1.0	0.4	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.006	0.087
Natural reveg.		0.001

Analysis of Variance for Test of Differences in Corn Growth from Time 1 to Time 2

Dependent Variable: Percentage Cover

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	5.61	1.87	0.11	0.952
Time	1	0.00	0.00	0.00	1.000
Error	3	53.22	17.74		
Total	7	58.83			

R-Square	CV	Root MSE	Percentage Cover Mean
0.10	4.33	4.21	97.25

Dependent Variable: Plant height

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	1699.82	566.61	5.11	0.107
Time	1	0.13	0.13	0.00	0.975
Error	3	332.93	110.98		
Total	7	2032.88			

R-Square	CV	Root MSE	Plant height Mean
0.84	14.28	10.53	73.79

Dependent Variable: Aboveground Biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	117814	39271	3.96	0.144
Time	1	748	748	0.08	0.802
Error	3	29743	9914		
Total	7	148305			

R-Square	CV	Root MSE	Aboveground Biomass Mean
0.80	19.33	99.57	515

Dependent Variable: Root Mass

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	427	142	2.26	0.260
Time	1	1482	1482	23.54	0.017
Error	3	189	63		
Total	7	2098			

R-Square	CV	Root MSE	Root Mass Mean
0.91	16.61	7.93	47.78

Dependent Variable: Root Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	1293723	431241	4.67	0.119
Time	1	1347271	1347271	14.58	0.032
Error	3	277175	92392		
Total	7	2918170			

R-Square	CV	Root MSE	Root Length Mean
0.905017	15.6881	303.96	1937.52

Dependent Variable: Root surface area

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	32840	10947	9.94	0.046
Time	1	45268	45268	41.12	0.008
Error	3	3303	1101		
Total	7	81411			

R-Square	CV	Root MSE	Root surface area Mean
0.96	10.72	33.18	309.52

Dependent Variable: Average root diameter

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	0.00192	0.00064	0.43	0.749
Time	1	0.00013	0.00013	0.09	0.788
Error	3	0.00452	0.00151		
Total	7	0.00658			

R-Square	CV	Root MSE	Average root diameter Mean
0.31	7.48	0.04	0.52

Dependent Variable: Root length density

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Plot	3	1.64	0.55	1.73	0.332
Time	1	1.55	1.55	4.91	0.114
Error	3	0.95	0.32		
Total	7	4.14			

R-Square	CV	Root MSE	Root length density Mean
0.77	22.14	0.56	2.54

Comparisons of Least Squares Treatment Means from Two Corn Crops

Time	Percentage Cover lsmean	Standard Error	Pr > |t|
1	97.3	2.1	1.00
2	97.3	2.1	

Time	Plant Height lsmean	Standard Error	Pr > |t|
1	73.9	5.3	0.975
2	73.7	5.3	

Time	Aboveground biomass lsmean	Standard Error	Pr > |t|
1	524.7	49.8	0.802
2	505.3	49.8	

Time	Root mass lsmean	Standard Error	Pr > |t|
1	61.4	4.0	0.017
2	34.2	4.0	

Time	Root length lsmean	Standard Error	Pr > |t|
1	2348	152	0.032
2	1527	152	

Time	Root surface area lsmean	Standard Error	Pr > |t|
1	385	17	0.008
2	234	17	

Time	Average root diam. lsmean	Standard Error	Pr > |t|
1	0.51	0.02	0.788
2	0.52	0.02	

Time	Root length density lsmean	Standard Error	Pr > |t|
1	2.98	0.28	0.114
2	2.10	0.28	

Analysis of Variance for Plant Assessment Parameters
Tests of Treatment Differences Using the Sum of Two Corn Crops

Dependent Variable: Percentage Cover

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	138	46	7.66	0.018
Treatment	2	20276	10138	1682.71	<.0001
Error	6	36	6		
Total	11	20450			

R-Square	CV	Root MSE	Percentage Cover Mean
1.00	3.67	2.45	66.86

Dependent Variable: Plant height

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	1512	504	3.26	0.102
Treatment	2	1346	673	4.35	0.068
Error	6	927	155		
Total	11	3784			

R-Square	CV	Root MSE	Plant height Mean
0.76	15.54	12.43	80.01 cm

Dependent Variable: Aboveground biomass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	169782	56594	5.68	0.094
Treatment	1	479547	479547	48.15	0.006
Error	3	29880	9960		
Total	7	679209			

R-Square	CV	Root MSE	Aboveground biomass Mean
0.96	12.71	99.80	785.17 g/m^2

Dependent Variable: Root mass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	4601	1534	2.14	0.197
Treatment	2	18305	9153	12.74	0.007
Error	6	4309	718		
Total	11	27216			

R-Square	CV	Root MSE	Root mass Mean
0.84	33.99	26.80	78.84 g/m^2

Dependent Variable: Root length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	1364669	454890	1.48	0.313
Treatment	2	21631652	10815826	35.11	0.001
Error	6	1848475	308079		
Total	11	24844797			

R-Square	CV	Root MSE	Root length Mean
0.93	21.65	555.05	2563.46 gm

Dependent Variable: Root surface area

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	51037	17012	2.67	0.142
Treatment	2	523784	261892	41.05	0.000
Error	6	38280	6380		
Total	11	613102			

R-Square	CV	Root MSE	Root surface area Mean
0.94	20.10	79.88	397.41 cm^2

Dependent Variable: Average root diameter

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	0.0167	0.0056	16.7400	0.003
Treatment	2	0.0108	0.0054	16.2000	0.004
Error	6	0.0020	0.0003		
Total	11	0.0295			

R-Square	CV	Root MSE	Average root diameter Mean
0.93	3.68	0.02	0.50 mm

Dependent Variable: Root length density

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Plot	3	2.74	0.91	1.50	0.308
Treatment	2	38.04	19.02	31.13	0.001
Error	6	3.67	0.61		
Total	11	44.44			

R-Square	CV	Root MSE	Root length density Mean
0.92	22.51	0.78	3.47 cm/cm^3

Comparisons of Least Squares Treatment Means from Analysis Using the Sum of Two Corn Crops

Means followed by the same letter are not different by paired t-test.

Treatment	Percentage cover lsmeans	Standard Error	
Corn	97.3	1.2	a
Natural reveg.	94.6	1.2	a
Willow	8.8	1.2	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.175	<.0001
Natural reveg.		<.0001

Treatment	Plant Height lsmeans	Standard Error	
Corn	74	6	b
Natural reveg.	95	6	a
Willow	71	6	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.053	0.788
Natural reveg.		0.036

Treatment	Aboveground biomass lsmeans	Standard Error	H0:LSMean1= LSMean2 Pr > |t|
Corn	1030.00	49.90	0.006
Natural reveg.	540.33	49.90	

P values for paired t-tests:

Treatment	Root mass lsmeans	Standard Error	
Corn	96	13	a
Natural reveg.	116	13	a
Willow	25	13	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.321	0.010
Natural reveg.		0.003

Treatment	Root length lsmeans	Standard Error	
Corn	3875	278	a
Natural reveg.	3097	278	a
Willow	719	278	b

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.095	0.0002
Natural reveg.		0.001

Treatment	Root surface area lsmeans	Standard Error	
Corn	619.0	39.9	a
Natural reveg.	455.8	39.9	b
Willow	117.4	39.9	c

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.0277	0.0001
Natural reveg.		0.001

Treatment	Root diameter lsmeans	Standard Error	
Corn	0.52	0.01	a
Natural reveg.	0.45	0.01	b
Willow	0.52	0.01	a

P values for paired t-tests:

	Natural reveg.	Willow
Corn	0.002	0.807
Natural reveg.		0.003

Treatment	Root length density lsmeans	Standard Error	
Corn	5.08	0.39	a
Natural reveg.	4.35	0.39	a
Willow	0.99	0.39	b

P values for paired t-tests:

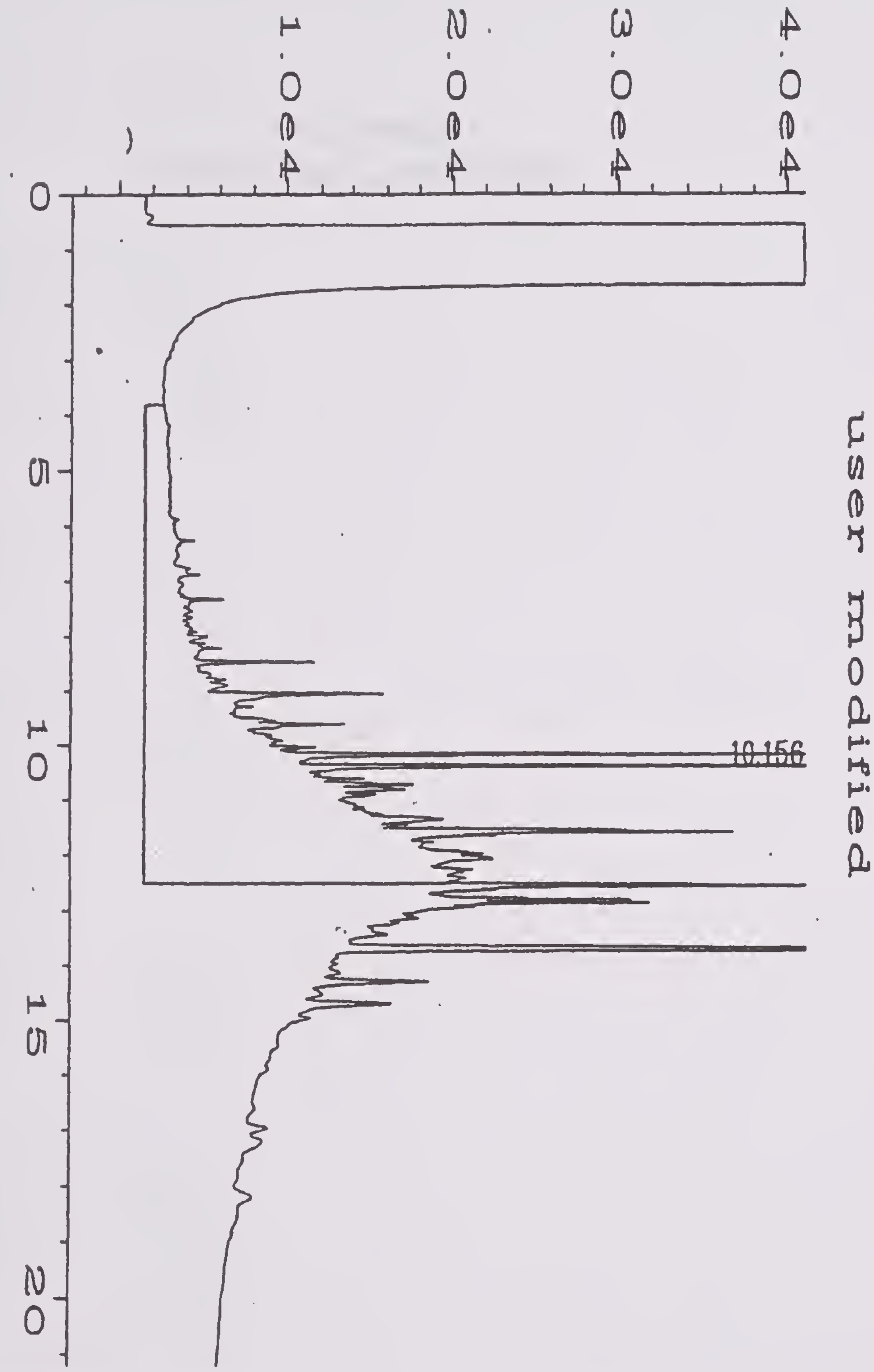
	Natural reveg.	Willow
Corn	0.239	0.0003
Natural reveg.		0.001

Appendix C
DRO Chromatograms

SUPPRESSION

T = O

DRO = 84 mg/kg

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Instrument         : DRO                          Vial Number        : 19
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Run Time Bar Code  :                              Sequence Line      : 3
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Report Created on: 26 Jun 01   04:03 PM           Analysis Method    : 1QUICKMN.MTH
Last Recalib on    : 20 JUN 93 01:52 PM           Sample Amount      : 0
Multiplier         : 1                            ISTD Amount        :
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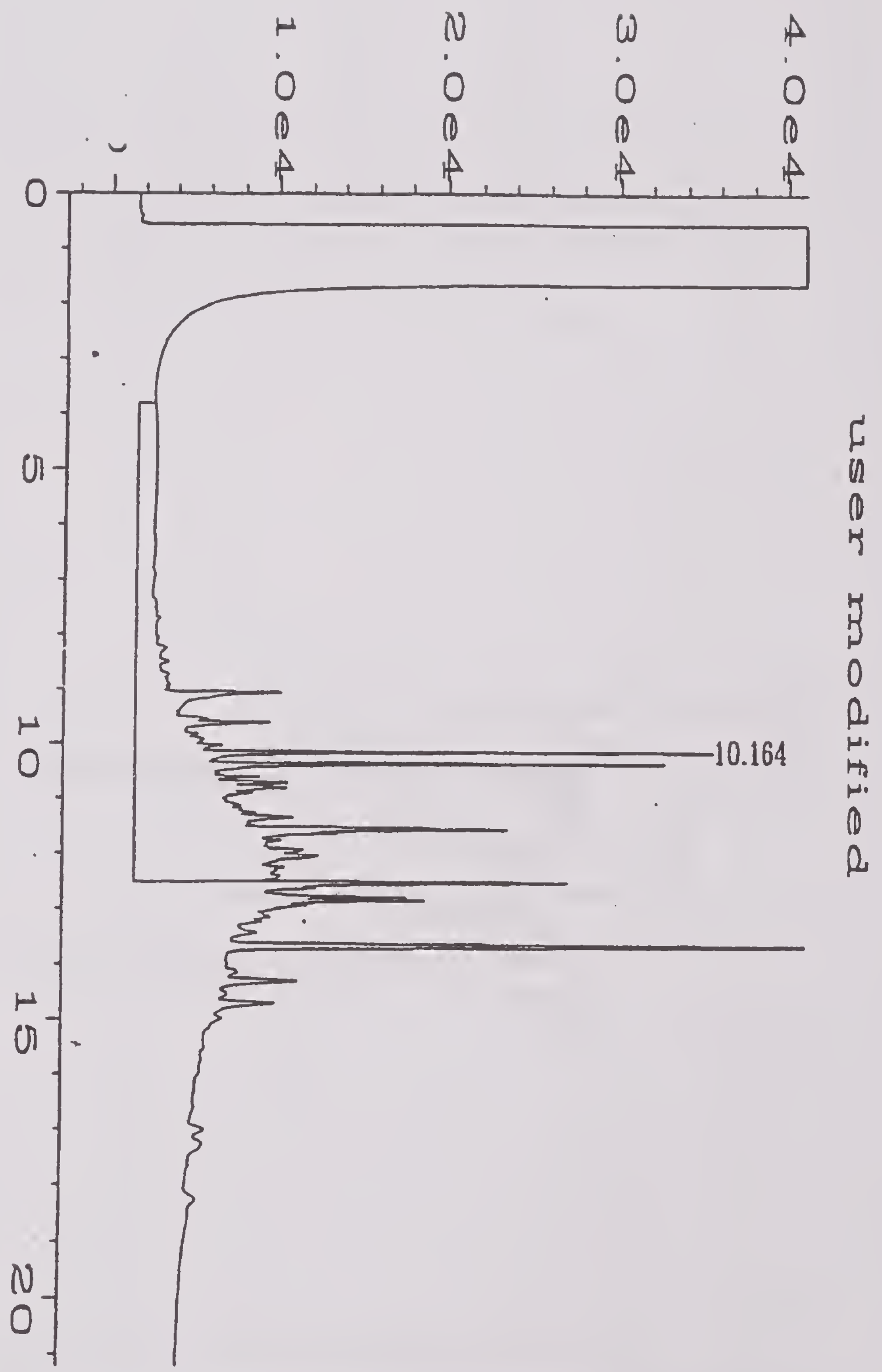
WILLOW

T = 0

DRO = 35 mg/kg



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Run Time Bar Code	:	Sequence Line	: 2
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Report Created on	: 26 Jun 01 01:51 PM	Analysis Method	: 1QUICKMN.MTH
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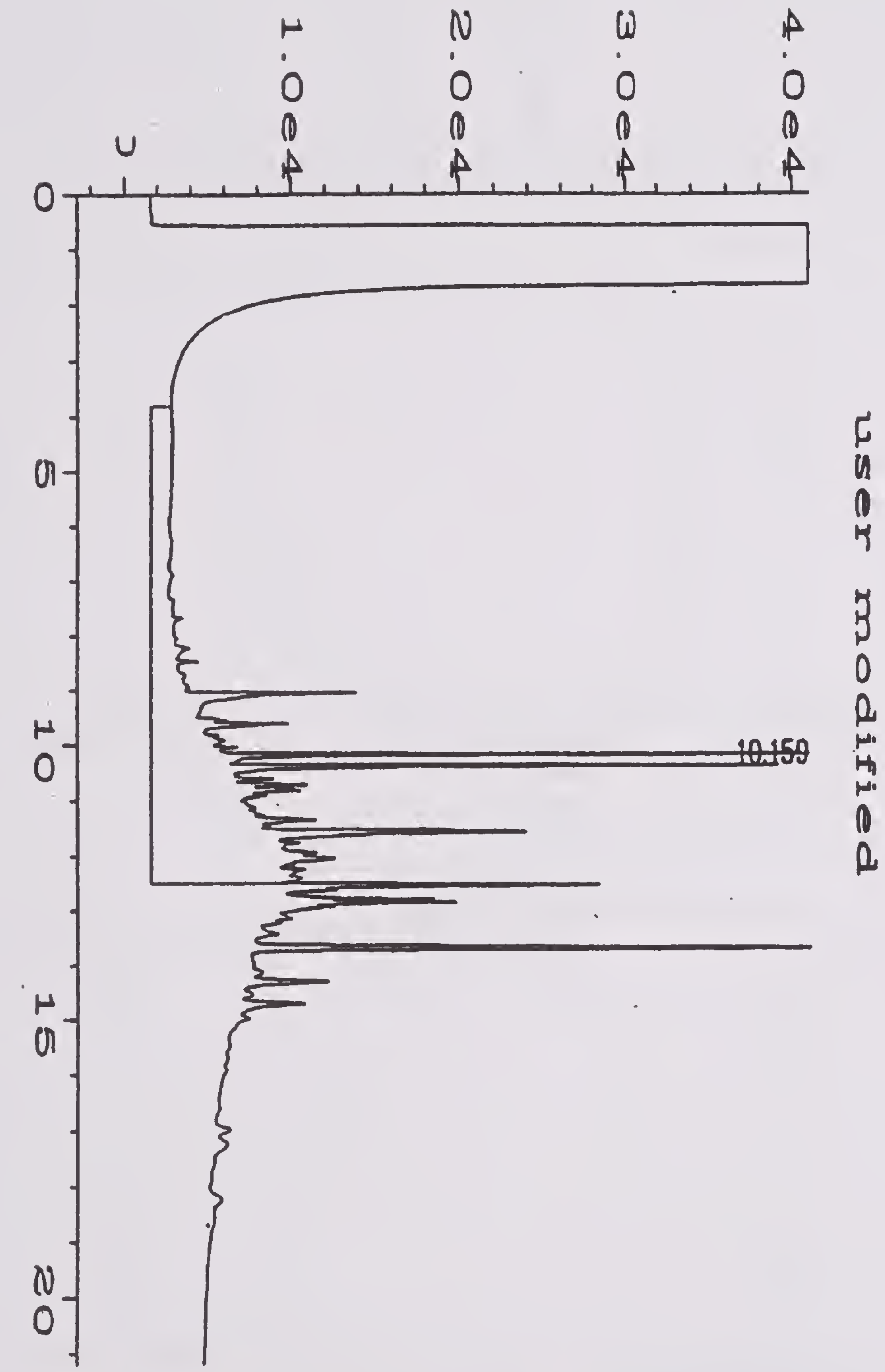
Multiplier	: 1	ISTD Amount	:

NATURAL VEG

T = 0

DRO = 38 mg/kg



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Run Time Bar Code	:	Sequence Line	: 2
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Report Created on	: 26 Jun 01 01:53 PM	Analysis Method	: 1QUICKMN.MTH
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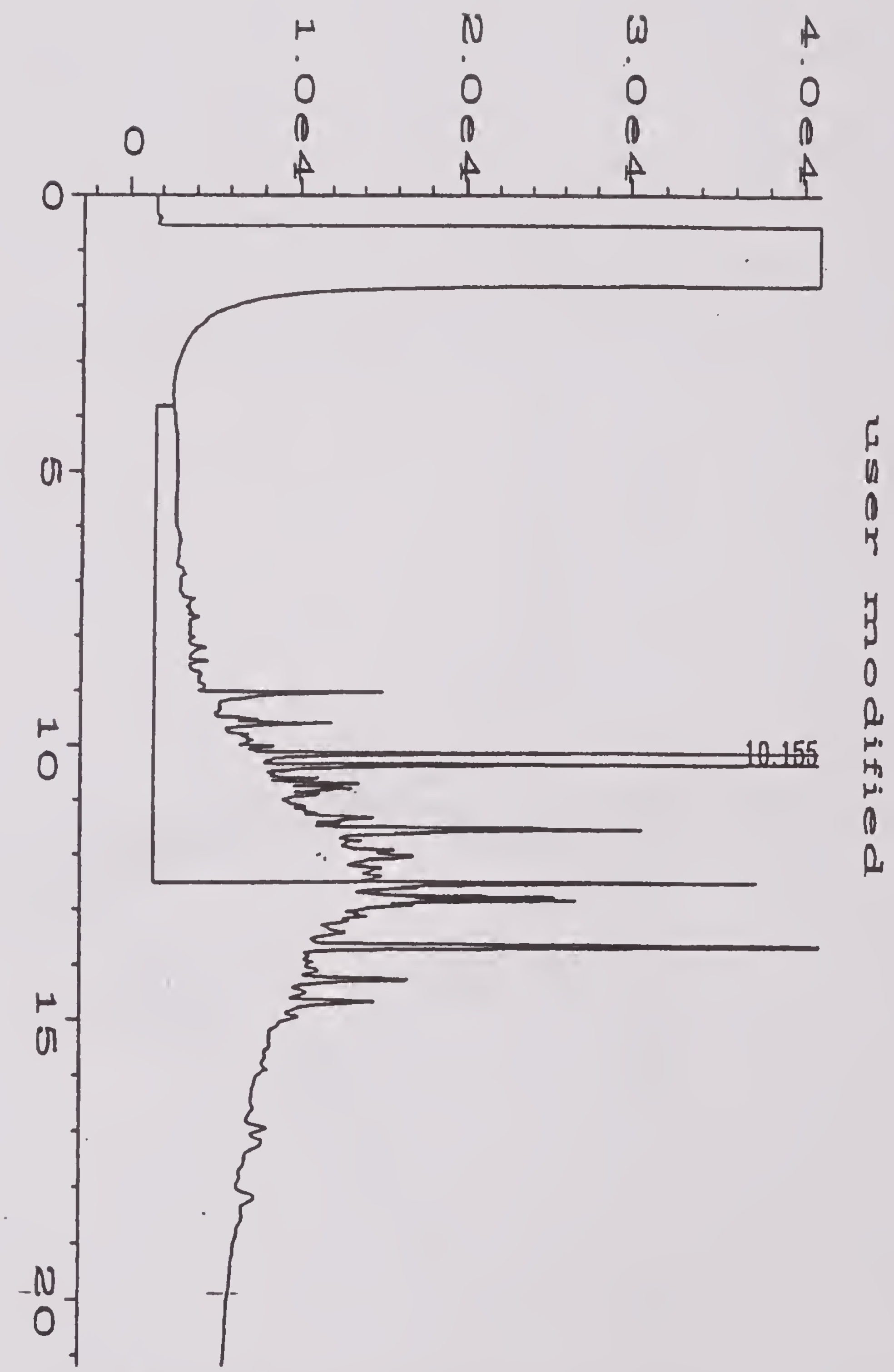
Multiplier	: 1	ISTD Amount	:

CORN

T = 0

DRO = 47 mg/kg



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Report Created on	: 26 Jun 01 04:29 PM	Analysis Method	: 1QUICKMN.MTH
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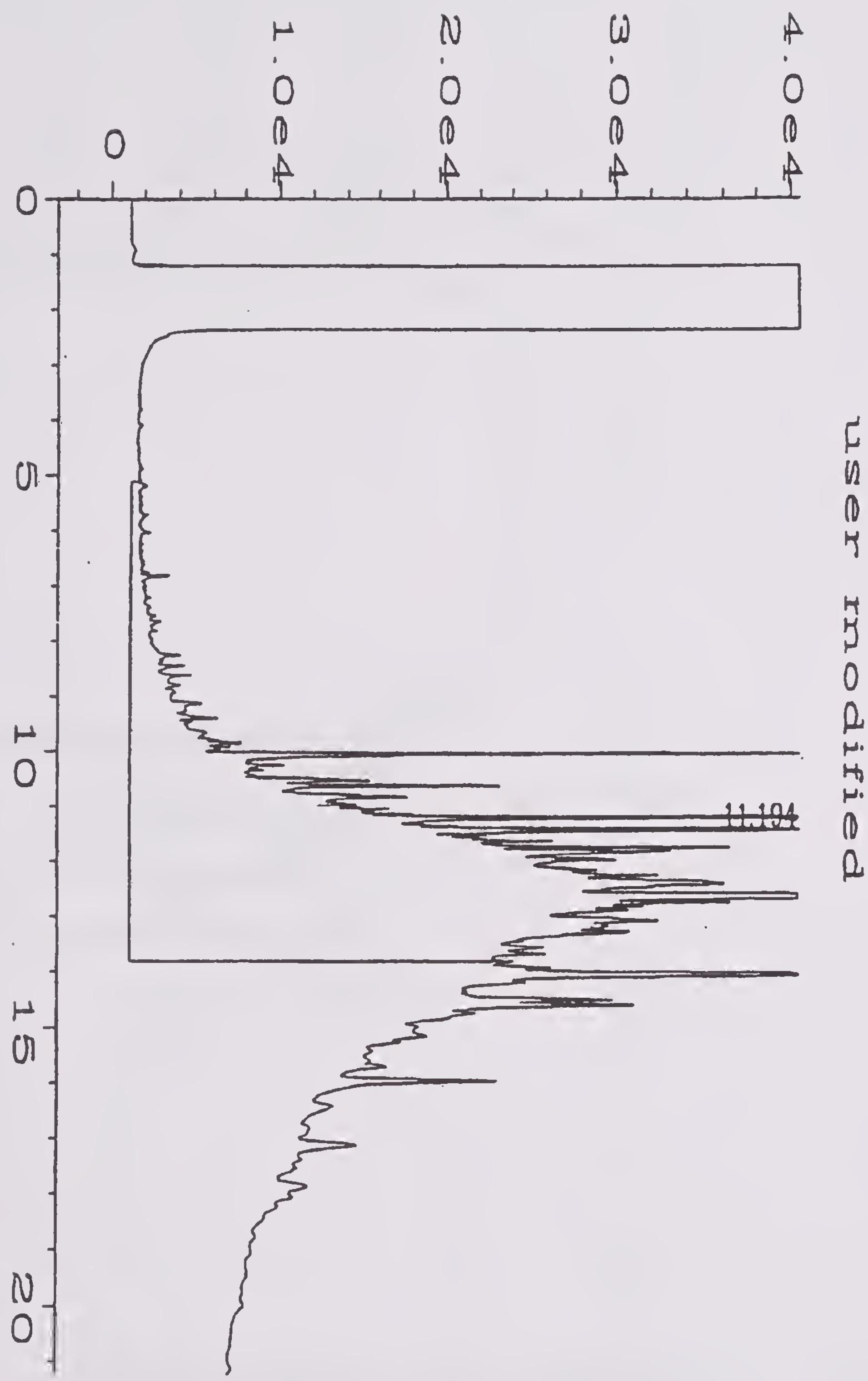
Multiplier	: 1	ISTD Amount	:

SUPPRESSION

T = 1

DRO = 340 mg/kg

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Sample Name       : 22695D012SWR2.5            Injection Number  : 1
Run Time Bar Code:                             Sequence Line     : 1
Acquired on       : 03 Jun 02  01:10 PM        Instrument Method: 1QUICKMN.MTH
Report Created on: 03 Jun 02  01:36 PM         Analysis Method  : 1QUICKMN.MTH
Last Recalib on   : 20 JUN 93 01:52 PM         Sample Amount     : 0
Multiplier        : 1                          ISTD Amount       :
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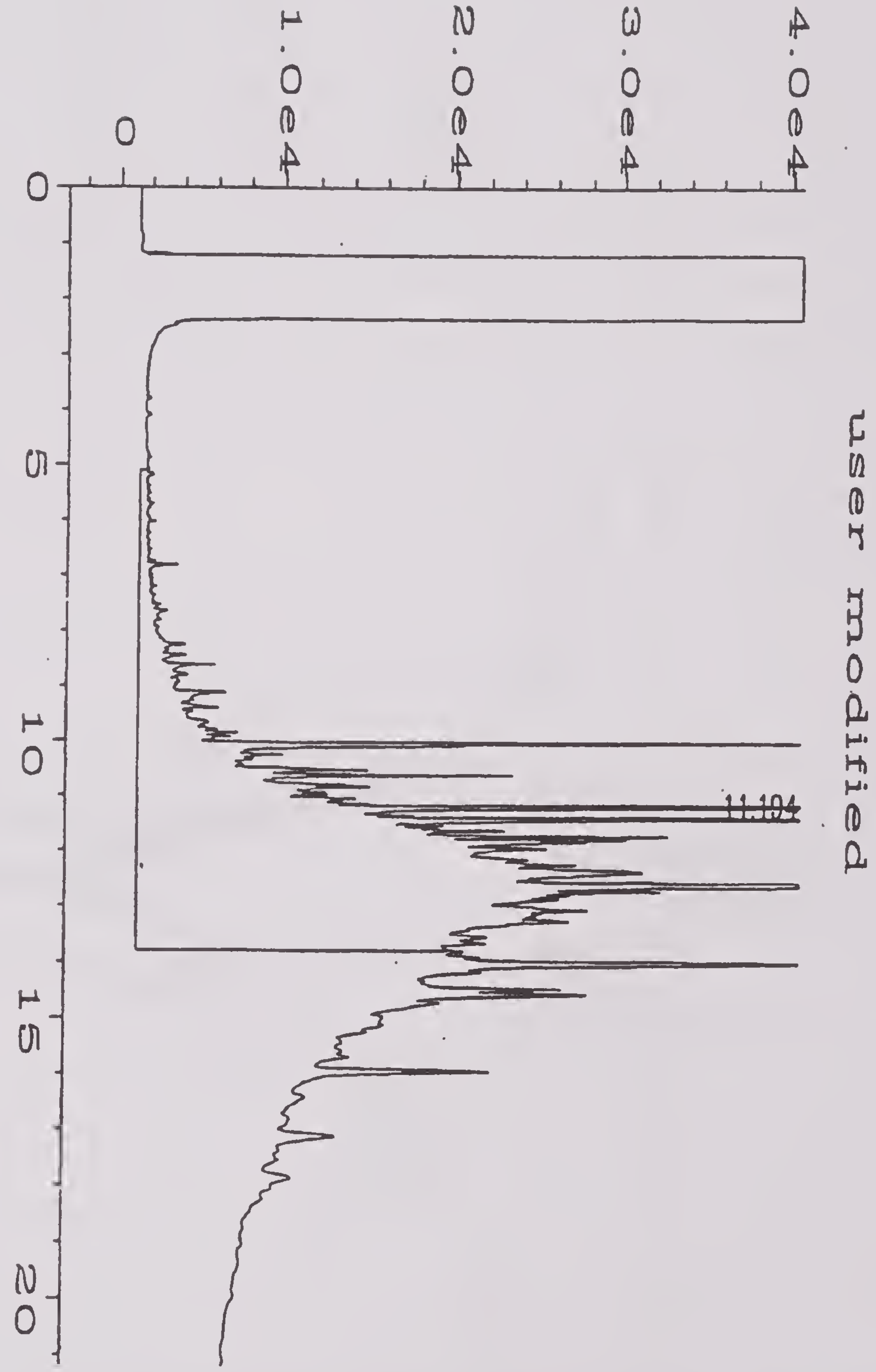
WILLOW

T = 1

340 mg/kg



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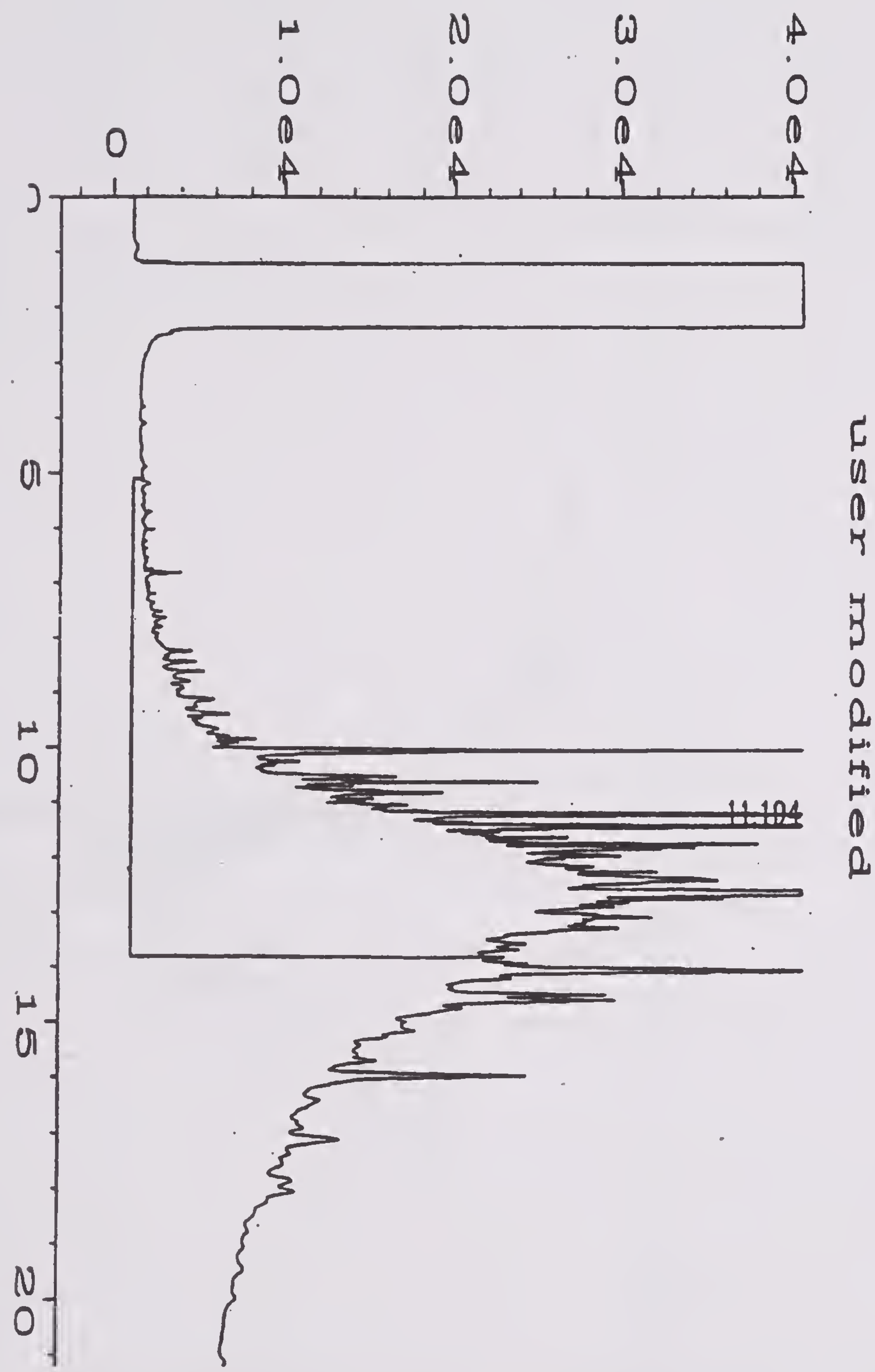
Run Time Bar Code	:	Sequence Line	: 1
Acquired on	: 03 Jun 02 01:36 PM	Instrument Method	: 1QUICKMN.MTH
Report Created on	: 03 Jun 02 02:02 PM	Analysis Method	: 1QUICKMN.MTH
Last Recalib on	: 20 JUN 93 01:52 PM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:

NATURAL VEG

T = 1

DRO = 340 mg/kg



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Sample Name	: 22695D011SWR2.5	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 03 Jun 02 12:44 PM	Instrument Method:	1QUICKMN.MTH
Report Created on:	03 Jun 02 01:10 PM	Analysis Method	: 1QUICKMN.MTH
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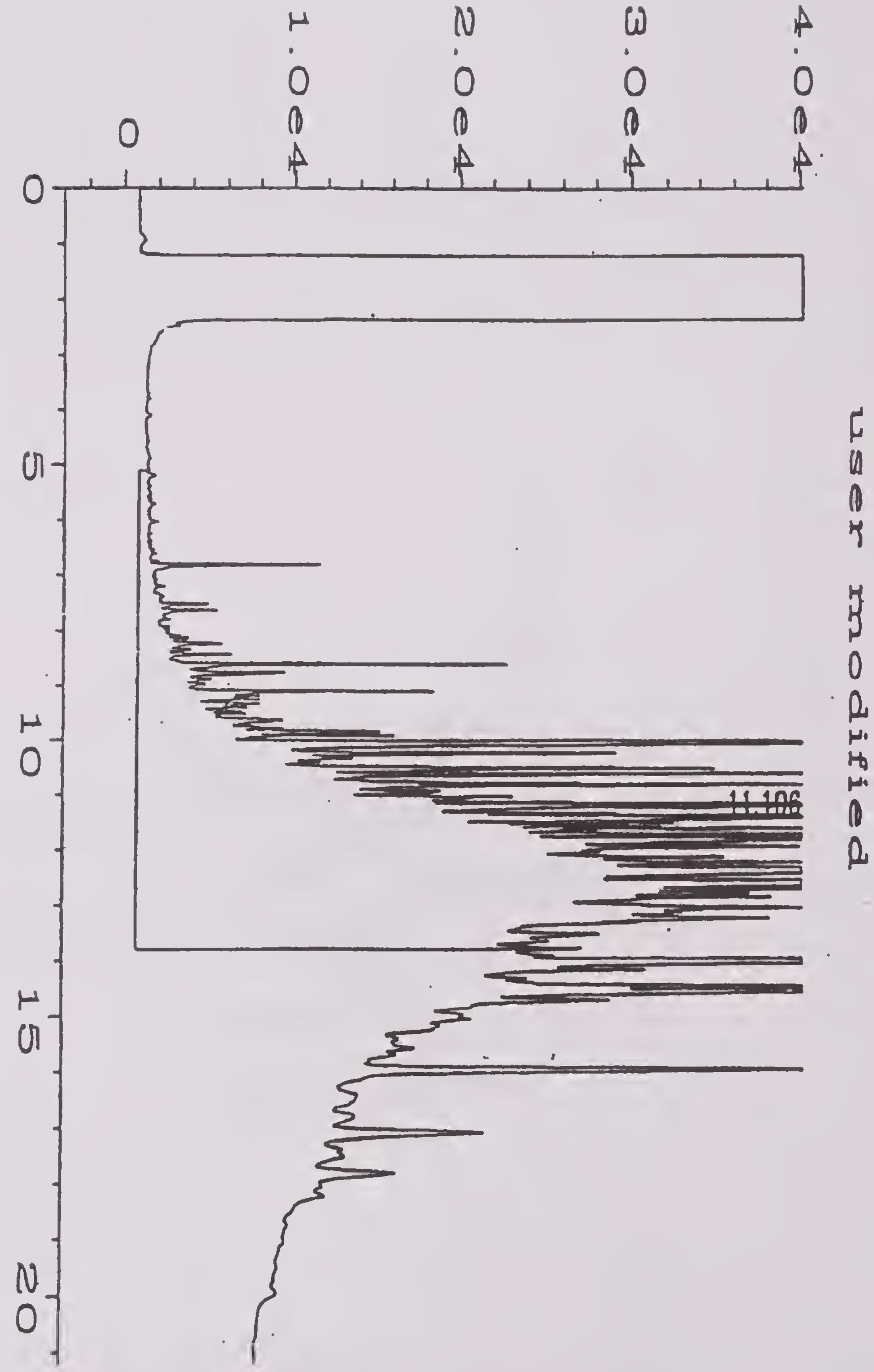
Multiplier	: 1	ISTD Amount	:

CORN

T = 1

DRO = 200 mg/kg



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Report Created on	: 31 May 02 05:24 PM	Analysis Method	: 1QUICKMN.MTH
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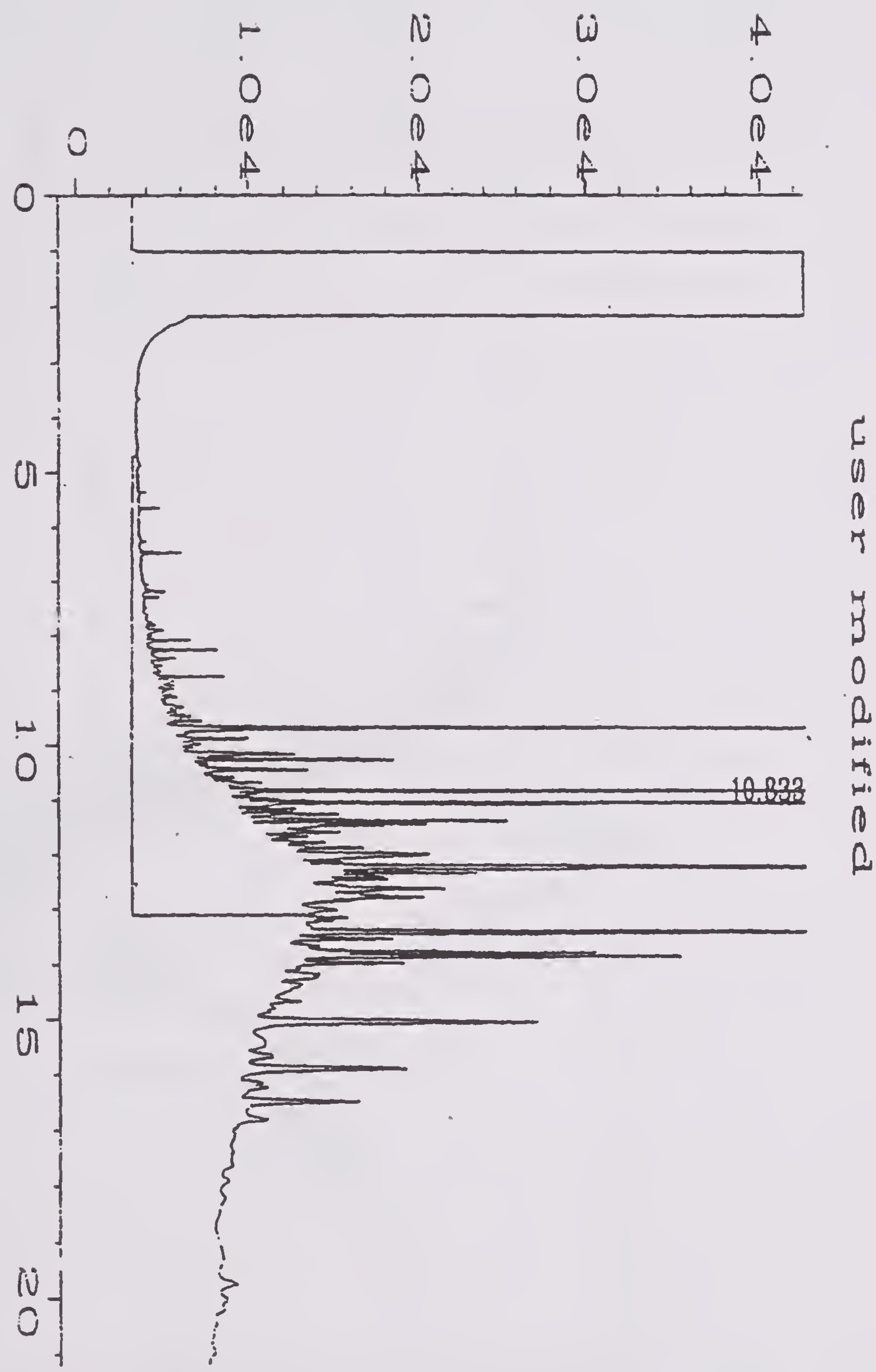
Multiplier	: 1	ISTD Amount	:

SUPPRESSION

T = 2

DRO = 120 mg/kg



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Report Created on	: 27 Sep 02 01:37 PM	Analysis Method	: 1QUICKMN.MTH
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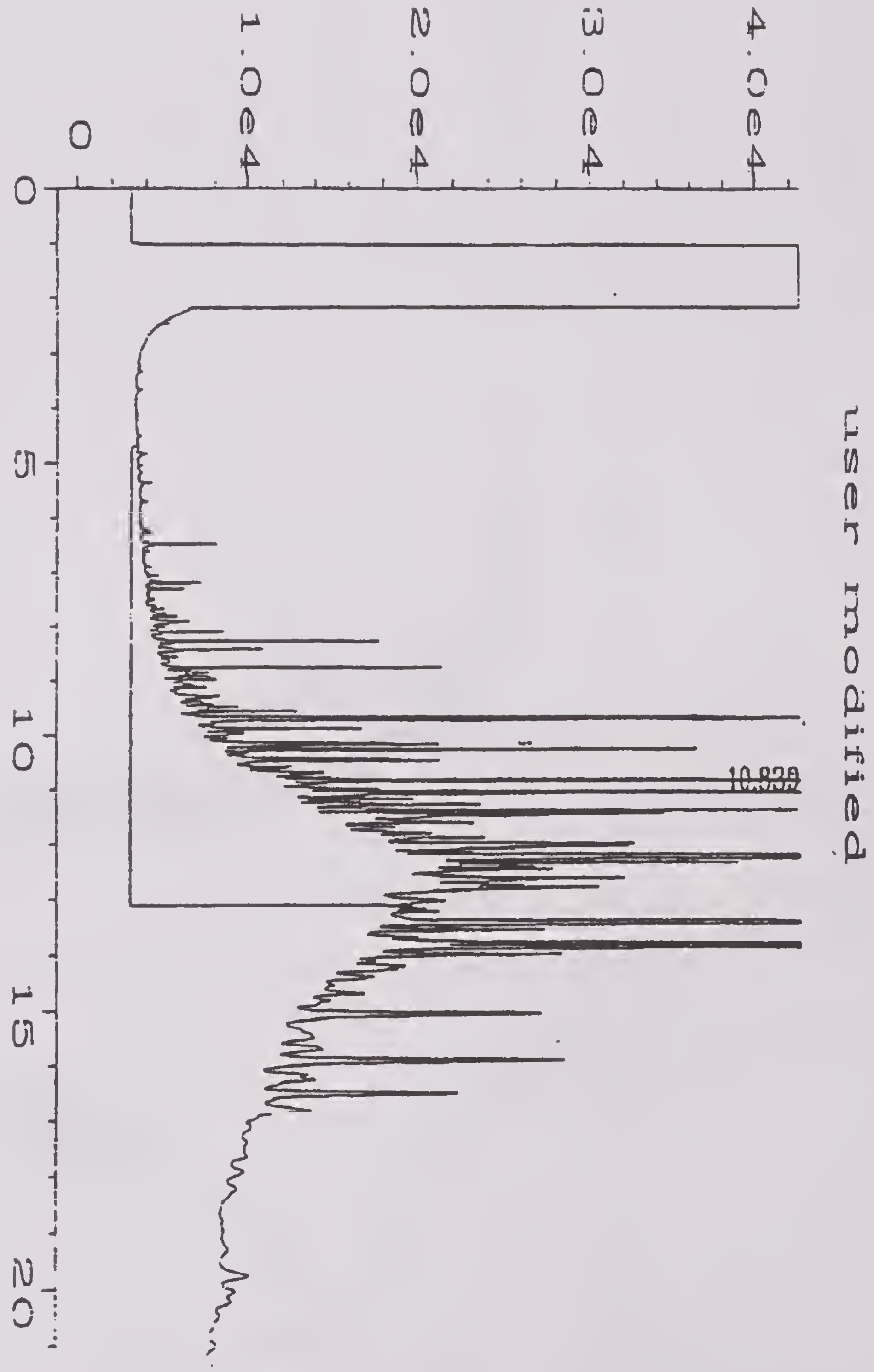
Multiplier	: 1	ISTD Amount	:

WILLOW

T = 2

DRO = 220 mg/kg



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Run Time Bar Code:			Sequence Line	:	1
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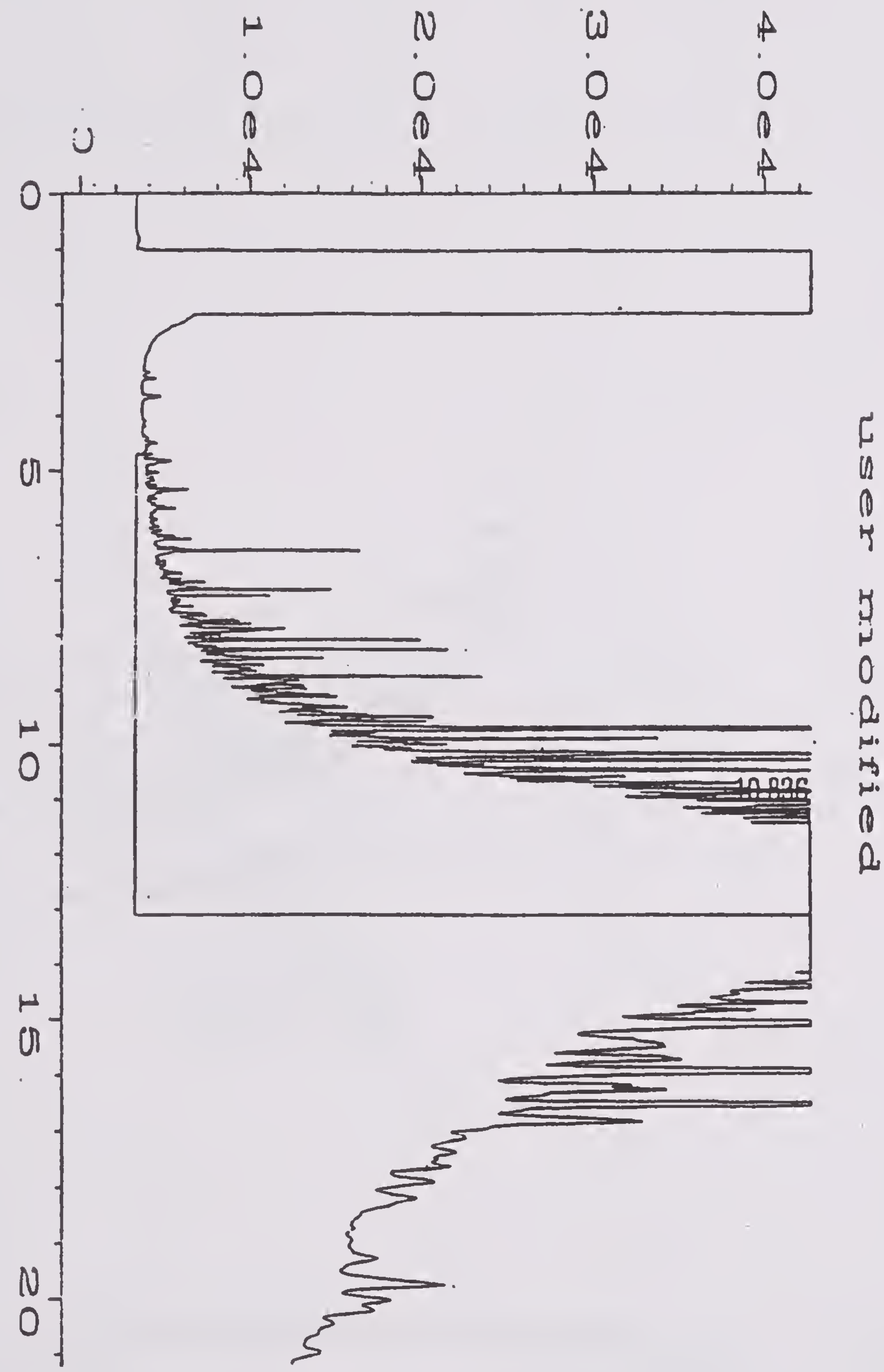
Report Created on:	27 Sep 02 06:28 PM		Analysis Method	:	1QUICKMN.MTH
Last Recalib on	: 20 JUN 93 01:52 PM		Sample Amount	:	0
Multiplier	: 1		ISTD Amount	:	

NATURAL VEG

T = 2

DRO = 150 mg/kg



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Sample Name	: 26159D011SFR1		Injection Number	:	1
Run Time Bar Code	:		Sequence Line	:	1
Acquired on	: 27 Sep 02 11:52 AM		Instrument Method	:	1QUICKMN.MTH
Report Created on	: 27 Sep 02 12:18 PM		Analysis Method	:	1QUICKMN.MTH
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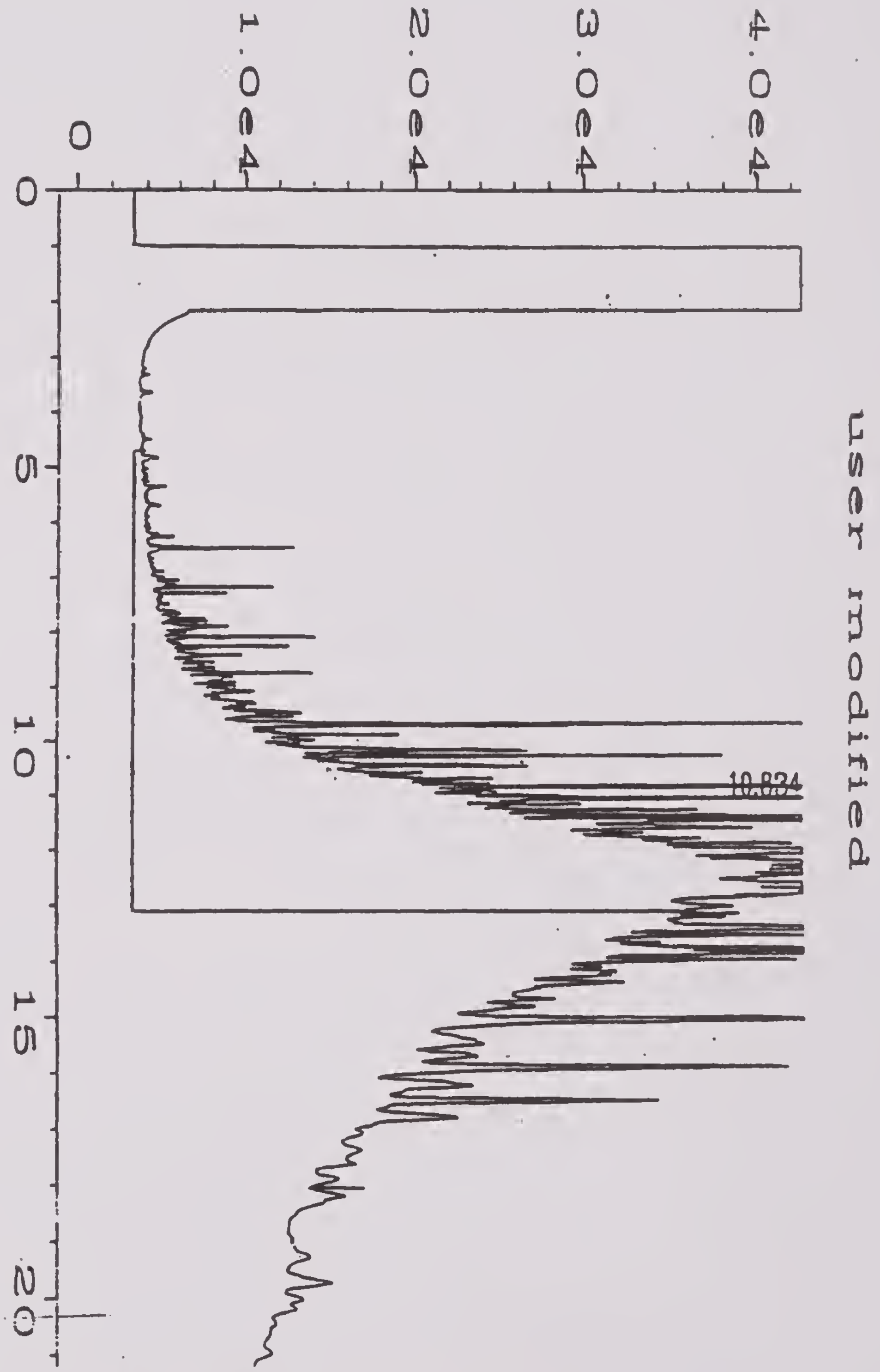
Multiplier	: 1		ISTD Amount	:	

CORN

T = 2

DRO = 180 mg/kg



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Last Recalib on	: 20 JUN 93 01:52 PM		Sample Amount	: 0
Multiplier	: 1		ISTD Amount	:

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